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OF

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(INSTITUTED 1852.)

VOL. LIV

PART C.

Being the third volume of the Publications of the
International Engineering Congress,
held under the auspices of the Society,
St. Louis, Mo., October 3d to 8th, 1904.

Edited by the Secretary, under the direction of the Committee on Publications.

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1905.

INTERNATIONAL ENGINEERING CONGRESS, 1904.

Organization and Scope.—The Congress was undertaken, financed and conducted by the American Society of Civil Engineers, at the request of the Louisiana Purchase Exposition. Thirty-seven subjects were selected for consideration, and invitations to contribute papers were issued to specially selected engineers in America and abroad ; each of these papers to be a review of progress during the past decade.

Papers and Discussions.—In response to this invitation ninety-seven such papers were received, nearly all of which were printed in advance form and distributed prior to the Congress for the purpose of eliciting discussion. The nationality of the authors of these papers is as follows :

United States, 51,	Holland, 7,	Belgium, 1,	Russia, 1,
France, 18,	Japan, 5,	Canada, 1,	Switzerland, 1.
England, 10,	Austria, 1,	Denmark, 1,	

One hundred and twenty-four additional written communications have also been received, which, together with the oral discussions at the Congress, after revision by the speakers, form part of this Congress publication.

Meetings.—The Congress was divided into eight Sections: Waterways, Municipal, Railroads, Materials of Construction, Mechanical, Electrical, Military and Naval, and Miscellaneous, and twenty-eight sectional meetings were held. There were also two general meetings of the Congress. The total registered attendance was 876, and the average attendance at each sectional meeting about 50.

Publications.—This Volume is one of six containing the Papers and Discussions of the Congress, published by the Society as Parts A, B, C, D, E, and F, of Vol. LIV of *Transactions.* In these volumes although it has not been possible to retain the subdivision by Sections, and no special grouping of subjects has been attempted, the papers and discussion on each subject are grouped. With each volume there is a table of Contents, and the last volume contains an Index covering the entire publication.

CHAS. WARREN HUNT,
Secretary.

NEW YORK, FEBRUARY 25TH, 1905.

INTERNATIONAL ENGINEERING CONGRESS.

ST. LOUIS, MO., OCTOBER 3d TO 8th, 1904.

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ST. LOUIS, MO., OCTOBER 3d TO 8th, 1904.

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AMERICAN SOCIETY OF CIVIL ENGINEERS.

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TRANSACTIONS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

IRRIGATION.

Congress Paper No. 31.

IRRIGATION UNDER BRITISH ENGINEERS.

BY MAJOR SIR HANBURY BROWN, K. C. M. G., M. INST. C. E., LATE R. E., Crawley Down, England.

Congress Paper No. 32.

IRRIGATION IN JAVA.

BY J. E. DE MEYIER, LATE DIRECTOR OF PUBLIC WORKS, IN NETHERLANDS' INDIA, The Hague, The Netherlands.

Congress Paper No. 33.

IRRIGATION IN THE UNITED STATES.

BY ELWOOD MEAD, M. AM. SOC. C. E., Washington, D. C., U. S. A.

Congress Paper No. 34.

IRRIGATION AND HYDRAULIC MOTORS USED IN IRRIGATION IN FRANCE.

BY PAUL LÉVY SALVADOR, INGÉNIEUR DES CONSTRUCTIONS CIVILES; INGÉNIEUR AU MINISTÈRE DE L'AGRICULTURE, Paris, France.

Congress Paper No. 35.

IRRIGATION IN THE HAWAIIAN ISLANDS.

By M. O'Shaughnessy, M. Am. Soc. C. E.,
San Francisco, Cal., U. S. A.

Discussion of the Subject by

Sir Thomas Higham, Bristol, England.
Gen. F. H. Rundall, Llanbedr, North Wales.
C. J. Grant, Mildura, Victoria.
Michael Elliot, Melbourne, Victoria.
Alfred Chatterton, Madras, India.
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H. D. Pearsall, London, England.
L. J. Le Conte, Oakland, Cal., U. S. A.
David M. Duller, Houston, Tex., U. S. A.
Sir Hanbury Brown, Crawley Down, England.
Paul Lévy Salvador, Paris, France.
J. E. de Meyier, The Hague, The Netherlands.

Note.—Figures and Tables in the text are numbered consecutively through the papers and discussion on each subject.

TRANSACTIONS
AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,
1904.

Paper No. 31.

IRRIGATION.

IRRIGATION UNDER BRITISH ENGINEERS.

By Major Sir Hanbury Brown,* K. C. M. G., M. Inst. C. E., Late R. E.

Introduction.

†This paper deals with irrigation in India and Egypt, the two schools in which hitherto all British irrigation engineers have got their practical training. The subject of India has been dealt with by Mr. R. B. Buckley, C. S. I., M. Inst. C. E., late Chief Engineer of Bengal, as his experience of Indian irrigation is longer, wider and more recent than the writer's.

As a consequence of the difference that exists in the climatic conditions of the two countries, there is a corresponding difference in the system of canal administration. There is so little rain in Egypt that without irrigation there can be no crops. In India, on the other hand, the rainfall, though precarious, is, in some seasons and in certain localities, sufficient for the crops. Hence, in such places, it is a matter of choice based on speculation, whether canal

* Late Inspector General of Irrigation in Egypt.
† W. W. (1); R. B. B. (2).

water is taken or not. If taken, it must be paid for. Consequently, the areas of crop irrigated have to be measured yearly, and a permanent staff has to be kept for the purpose. The system necessitates a number of forms and elaborate checks, harassing for both those who collect and those who pay the water-rates. But in Egypt there are no separate water-rates, the payment of the land tax conferring the right to a water supply. For irrigation is an absolute necessity for all farming, and without it there would be no collections of land tax. So all cultivable land is taxed, and if, in consequence of a low flood, or from other causes for which the farmer is not responsible, water is not available for raising a crop on cultivable land, the land tax is remitted on the un-irrigated area. But remissions of this nature are exceptional and no special staff has to be maintained to make the necessary measurements. *The land tax, according to a re-assessment lately made, is fixed at a little less than one-third of the renting value of the land, subject to a maximum rate of £1 12 6 an acre. The average land tax is 15 shillings an acre.

As the subject of "Irrigation" is a large one, and limits have been assigned to this paper, references are given in foot notes to the various publications in which fuller information may be found. A list of these publications is appended.

INDIA.

†The oldest artificial systems of irrigation are, probably, those which arose, mainly from the natural action of the floods of the Euphrates and the Nile, in the lands of Mesopotamia and Egypt. But in India, also, in the Valley of the Indus, the regular annual rise of the river induced periodical floodings of lands, situated at suitable levels, by the action of Nature alone. The inhabitants on the banks of the Indus soon learnt to excavate small channels through the lands on the river bank, which were higher than those further from the stream, with the object of introducing the rising water of the river to lands which it did not naturally reach, or reached only at too late a date; and so these people commenced the vast system of canals, called inundation canals, which have tapped

* W. W. (1), p. 390.
† R. B. B. (2.)

the Indus for unknown ages. In Madras, on the other side of India, the earliest works were mainly tanks, many of them of considerable size, which were constructed by throwing earthen embankments across gorges to impound the drainage. Many of these tanks, which were constructed more than two thousand years ago, are still efficient. Some of them were supplied with masonry sluices to draw off the water at the time when it was required, but, in most cases, the regulation of the supply was effected by cuts made in the earthen bank of the reservoir, at various levels, as the water in the tank was drained off. In many other parts of India, besides Madras, surface-tanks were common and, more or less, efficient in protecting the crops, but all such works have the great defect that they are least efficient in years of small rainfall, when the water is most required. The century in which artificial irrigation was first practised in India must remain a matter of speculation; the introduction of it was probably, in many parts, contemporaneous with cultivation itself. One of the earliest historical references to it is to be found in the writings of Megasthenes, who, 300 years before Christ, described the benefit which was conferred on the people by the double crops they derived from irrigation. The earliest work of importance of which there is any record is the construction of the "Grand Anicut" on the Cauvery River in Madras, a stone weir 1 000 ft. long, 40 to 60 ft. broad and 15 to 18 ft. deep, which is said to have been built 200 years after Christ. It fulfilled its purpose for centuries and was still in effective operation in 1830, but changes in the river have since rendered it of much less importance.

In Northern India, Timur the Tartar, if he did many evil deeds, seems to have done some good by the interest he took in irrigation and the stimulus he applied to it by his laws. The earliest canals in that part, of which there is any record, are the perennial canals taking off the Jumna River. The one on the west bank, in the Punjab, is attributed to Firuz Shah, who, about the middle of the fourteenth century, is said to have cut a canal to irrigate his favourite hunting-grounds. The canal fell into disrepair, but was restored by the great Akbar in the sixteenth century. Again, early in the seventeenth century, the Emperor Shah Jehan carried the canal by aqueducts and a deep rock cutting into Delhi. The Eastern Jumna Canal, on the east bank of the river, was commenced by Shah Jehan about the same time.

Irrigation by means of "karezes" had been practised in Baluchistan, it is believed, for centuries before the same system was introduced in Italy under the name of "fontanelli." A "karez" is a tunnel driven into the ground, generally into a hillside, to tap the underground springs. The Baluchis are most clever in selecting suitable sites and in driving these headings. They run them sometimes for miles with occasional shafts rising to the surface. It is claimed for the water of the "karez" that it is far better for crops than the water of surface streams, as the temperature is higher. In the Himalayas, the hillsides, in parts, are bright with little streams, cleverly aligned on contours, which run from the beds of torrents to the patches of cultivation, which are terraced by the natives on the gentler slopes. Such little canals are very old.

So, India, long before the British engineer brought his level and theodolite to bear, knew the value and practised the art of irrigation, and the British engineer had, first, to learn, before he essayed to teach.

By far the greater part of the rainfall of India is due to the southwest monsoon, which occurs between June and October; indeed, in the Bombay Presidency it may be said that the rainfall is practically restricted to that season. The latter part of the cold weather and earlier spring months are the times of the winter rainfall in Northern India. The extreme northwestern districts receive, at that time, about half their annual fall. During the hot weather months, March to May or June, thunder-storms are not uncommon in parts, but generally the greater portion of India is without rainfall at that time. The intensity of the rainfall varies enormously; as the clouds drift eastward from the summit of the western hills the rainfall drops almost suddenly from 100 to 25 in. in the year, and a long tract of land is left extending from Rajputana to Cape Comorin in which the rainfall is scanty and precarious. *The average rainfall of the whole of India is about 42 in., and, taking the country as a whole, the rainfall does not vary greatly from year to year. But, in particular tracts, in themselves large areas, the rainfall is subject to very great variation, and, speaking generally, it may be said that, the smaller the average rainfall of any tract is, the greater is the probability that the fall will be below the

* S. M. (4).

average. When the average rainfall is 10 to 12 in. only, cultivation is almost impossible without irrigation—there are some 150 000 to 200 000 sq. miles in this condition—and, on the other hand, when the rainfall exceeds 70 in., as it does in Eastern Bengal and Assam, there is hardly ever any necessity for irrigation at all. Intermediate between these two conditions there is a tract of almost 1 000 000 sq. miles where irrigation alone can secure the country from an occasional loss of its crops, although such loss will never occur simultaneously over all the area.

*The alluvial formation covers the greater part of Northern India from the Himalayas to the Vindhyas, and extends in a narrow fringe round the coast line of the peninsula. The substrata consist usually of alternate layers of sand and clay; the surface shews every variety of soil from the blown sands of the western deserts to the rich loam of the Ganges Valley, and of the Kistna and Godaveri Deltas. The prevailing soil is a yellow or red-brown loam which yields a largely increased out-turn under irrigation.

The trap formation covers an area of about 200 000 sq. miles lying in the Bombay Presidency, Berar, and partly in the Central Provinces, Hyderabad and Central India. When dried by the heat of the sun, the soil contracts, in some cases, to an unusual extent, seaming the country with cracks to a depth of several feet. To the black cotton soils generally, irrigation is not suited, but to many soils it can be applied freely where the substratum affords good natural drainage.

The crystalline and sandstone formation may be said to occupy nearly the whole of the Madras Presidency and large portions of Bengal and of the other Provinces, except Bombay. *The prevailing soils vary from a dark red loam to a light sandy soil on the uplands. The better classes of soils in this formation repay the cost of irrigation even more abundantly than the yellow loam of the alluvial tract.

Each of these three great divisions of the soil has its own distinctive features as regards irrigation. The level surface of the alluvial plains allows of the absorption of a large percentage of the rainfall, and consequently wells, in most parts, give a good supply. These plains are traversed by the great rivers, and their level

*S. M. (4).

surface gives great facilities for distributing the waters over the land. These facilities are so pronounced that all the greatest canal systems of India lie in the alluvial tracts. The area ruled by the trap formation is generally marked by broken and uneven surfaces; irrigation is confined, for the most part, to the more valuable crops, and irrigation works, except of the smallest kind, are rare. The crystalline tract is traversed by the large rivers which rise in the Western Ghauts, but, for the most part, their channels are deep and their gradients small, it is consequently not easy to utilize their waters outside their own narrow valleys, while the broken nature of the country increases the difficulty. Beyond the area which is commanded by these rivers in the crystalline tract, there are many tanks which collect the rainfall. The broken and undulating nature of the country gives facilities for their construction; but these works, though numerous, are, with few exceptions, of comparatively small size.

*In the alluvial tract 135 million acres are cropped, and 25% of the cultivated area is irrigated; in the trap formation 58 million acres are cropped and only 3.2% irrigated; in the crystalline formation 100 million acres are cropped and 15.5% of the cultivation is irrigated. The total area irrigated annually in the Indian Empire is about 53 million acres, of which 44 million lie in British India and the rest in Native States. Of the 44 million acres, about 42% are irrigated by works which are under the control of the State and 58% are irrigated by private works; more than half of this latter area is irrigated from wells, which can hardly be regarded as irrigation works in the ordinary sense of the words.

The work of British engineers on the irrigation works of India commenced early in the nineteenth century. During the administration of the Marquis of Hastings (1814-1823), the reconstruction of the old native canals on the Jumna in Northern India was commenced. In 1836, Sir Arthur Cotton constructed the "Upper Anicut" across the Coleroon River in order to maintain the level required for the full utilization of the "Grand Anicut," already mentioned, which is supposed to have been in use for some sixteen hundred years. In 1837, Captain Cautley, an artillery officer, was deputed to make an estimate for the construction of a canal from a

*S. M. (4).

tributary of the Jumna. These were the first efforts of British engineers. Subsequently, Sir Arthur Cotton designed the works which now irrigate more than two million acres in the Deltas of the Godaveri and Kistna, and Sir Proby Cautley prepared the scheme and directed the construction of the great Ganges Canal in Northwestern India, which was commenced in 1848. The names of these two men must always be honoured in connection with Indian irrigation works. They were the pioneers who encouraged others to advance and who led them on to construct the many great canals which are so beneficial and profitable both to the people and to the Government of the country.

But, although it is true that great progress has been made during the last half century, it is remarkable how small a percentage of the available supply of water in the country has been diverted for the benefit of man. It is a fact also, which those who are not acquainted with all the circumstances fail often to appreciate, that it is not physically possible to utilize for irrigation more than a comparatively small proportion of the gross water-supply. *It has been estimated that the water evaporated from the ground and that which sustains plant life and the moisture in the soil amounts to 59% of the gross rainfall of India; that 35% is carried to the sea by the rivers and only 6% is utilized in irrigation. It is commonly thought that a large proportion of the 35%, which is, in some sense, wasted, might either be directly diverted on the land or stored in reservoirs for future use. It has already been stated that, although there are great variations in the incidence of the rainfall, the total annual fall does not vary greatly; so that it is thought that arrangements might be made to divert the surplus of one part to supplement the deficiencies of the other. For instance, nearly 16% of the whole surface-flow of India is lost annually in the Arabian Sea from the steep slopes of the Western Ghauts. There is one work, which, by a bold design, taps the flow on the western side of the hills, and, by means of a tunnel through the hills, diverts the water on the eastern table-lands. But the opportunities for similar works are not numerous and the cost is high. In Northern India, again, the snows and glaciers of the Himalayas provide storage which man

*S. M. (4).

cannot hope to rival, and yet, as a recent Commission reported, only 9% of the volume of water which is provided by Nature is utilized for irrigation. In this region there are conditions which are exceptionally favourable to the effective utilization of the surface-flow in the rivers, and, although it is the tract in which the greatest progress has been made in the last 50 years, it is still possible to make large extensions of irrigation. But, if all the works, which are now conceived to be possible, are constructed in the Punjab and Sind, 60% of the surface-flow off the land must still escape by the rivers to the sea.

The matter of the possible storage of the surplus water, in years of plentiful rainfall, to provide irrigation in years of drought, is one which greatly attracts the lay mind of the philanthropist; but investigations have shewn that, in the vast majority of cases, it is not possible, at any practicable cost, to provide the amount of storage required. *It is often forgotten that, in the alluvial plains, storage, on any considerable scale, is not possible; when allowance is made for the natural losses, the area required for storage would be equal to that which might be benefited by the utilization of the water; again, as such irrigation is not always necessary, and as it is impossible to predict a year of drought, the reservoirs would have to be filled, every year, in the flood season, although for many years the water might not be really required. On the other hand, in the Western Ghauts, where there is assured rainfall at an altitude which would enable the water, stored in reservoirs, to be carried to tracts where it is often badly needed, the physical conditions are often difficult. Dams of great height would be generally essential, owing to the steep slopes of the valleys; the broken nature of the ground would demand expensive and tortuous delivery channels; cyclonic storms produce extreme floods for which most extensive escapes are necessary to provide protection to the reservoirs, and the construction of the reservoirs would in many cases involve the submergence of fertile lands and valuable village sites. All these considerations shew that although India may hope, yet, for a large extension in useful works of irrigation, she can never expect to utilize more than a small percentage of the water which now flows away to the sea.

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*S. M. (4).

During the last century the chief works undertaken in India by British engineers were the great perennial systems which draw their supply direct from the great rivers. In the Forties, the Delta works of the Cauvery and Godaveri in Madras, which have given such splendid results, first began to bring revenue to the State. In the Fifties, the Bari Doab Canal in the Punjab, the Ganges Canal in the Northwest Provinces, and the Kistna Delta system in Madras came into operation. In the Sixties, four canal systems in Bombay and two canals in Bengal were added to the list of works open for irrigation. In the Seventies, the Sone Canals in Bengal, the Lower Ganges and Agra Canals in the Northwest, and the Mutha and Nira systems in Bombay, began to collect revenue from their irrigation. In the Eighties, the Sirhind Canal, which irrigates more than a million acres, was in effective flow, and in the Nineties, the Chenab Canal, commanding and irrigating between 2 and 3 million acres was commencing its career of usefulness. In 1850, those irrigation works which were under the control of the Government irrigated about 3 or 4 million acres only. A quarter of a century later the area irrigated by State works had increased to about 10 million acres, and now, after another twenty-five years, the area is about 20 million acres. Three-quarters of this area is watered by canals entirely constructed by the British Government, and the rest by canals improved, extended and maintained by it. During the last half century the Government has expended about 30 millions sterling on these works. They include 38 large systems, which are technically known as "productive works," 5 systems known as "protective" and 73 "minor" systems. These works have an aggregate mileage of 44 000 miles of canals and distributaries.

The Chenab Canal is the latest of the great systems; it is the largest, and the most interesting from several points of view. It was originally commenced as an "inundation" canal, which was only in flow during the flood season. But it was soon proved that unless a weir was constructed across the Chenab River, from which the canal drew its supply, it would not be possible to prevent accumulations of silt which would completely choke the discharge. A weir across the river was consequently built, with a waterway of 4 000 lin. ft., divided by piers 10 ft. wide into eight lengths of about 500 ft. each. On the crest of each length there are iron shutters,

6 ft. high and 3 ft. wide, which can be dropped, when the river rises, by a let-go gear worked from the piers, and raised, when the floods subside, by a crane travelling on a railway fixed on the weir below the shutters. The canal, which takes off from the river immediately above the weir, has a base of 250 ft. It flows with a maximum depth of nearly 11 ft., and has been found in practice to discharge as much as 10 800 cu. ft. per sec. The canal commands the tract of country, known as the Rechna Doab, lying between the Ravi and Chenab Rivers in the Punjab. This tract is nearly all Crown land; it was, before the advent of the canal, almost entirely waste, with an extremely sparse and largely nomad population; some portion was wooded with jungle trees; some was covered with small scrub camel thorn; some was absolutely bare, producing only, on occasions, a brilliant mirage of unbounded sheets of fictitious water. Such was the country into which the engineers have led 400 miles of main canals and 1 200 miles of distributary to distribute the water over some two million acres of crops which now flourish on the lands which were barren and unproductive. The main canals and the branches run on the main ridges of the country, and the major distributaries are on the minor water-sheds; some of these are of considerable size, carrying as much as 500 cu. ft. per sec. As the tract was formerly almost uninhabited, villages had to be formed and settlers introduced. Each settler, on being installed, was practically guaranteed water for a certain portion of his holding, and, in order to ensure this, most elaborate demarcation and levelling of the lands were made. All the Crown lands were divided into squares of about 1 100 ft. side, and pillars were erected with a systematic series of numbers. These numbers were originally designed only for revenue purposes, but they were found to serve the subsidiary, but useful, purpose of land marks to guide the engineers over the immense and trackless wastes in which they used, occasionally, to lose themselves. About 1 500 000 acres of Crown lands have been allotted, and a new population of a million people have founded homesteads which they cultivate with the waters of the canal. In order to regulate the discharges of the various canals and distributaries, it has been found essential to have a telegraph line extending over the whole system. A railway has been made through the heart of the irrigated tract. There is one

feature in this canal system which is novel. The canals are so aligned that escapes back into the river are impossible, so that on a sudden reduction in the irrigation demand there is a difficulty in disposing of the supply which is flowing down the channels. Those who are conversant with the regulation of canals will appreciate the anxiety of an engineer, who knows that the canal above him is bringing down 11 000 cu. ft. per sec., and that he must in some way arrange to dispose of it. If he has no escapes and the cultivators decline to take the water on their fields, he knows that breaches in the canal bank must occur. On the Chenab Canal, in order to provide for the water in the canal, on such an occasion, seven depressions in the ground have been selected and surrounded with earthen banks; these form reservoirs into which the water can be turned until the reduction at the head, ordered by telegraph, can take effect. The Chenab Canal has cost rather less than £2 000 000; it commands 2 645 000 acres of cultivable land and has actually irrigated, in the year, nearly 2 000 000 acres.

Under the Indian system of canal administration direct payment is made by the people for the use of water for irrigation. One result of making a direct charge for the water is that it is possible to shew the financial results of the Indian works viewed simply as commercial undertakings, and this is done with reference to all the works of importance. The following figures shew the results of the three classes, "Productive," "Protective," and "Minor" works in the year 1902:

	Rupees.
Capital outlay to the end of the year on works in operation	441 211 545
Gross revenue during the year	42 605 102
Net revenue during the year after deducting all working expenses	27 834 799
Percentage of profit	6.31

If the 38 works classed as "Productive" are taken separately, the profit on them works out to 6.83 per cent. Among these 38, there are 13 works which are not remunerative, but the profit on the remaining 25, taken on their own capital, was 9.13% in the year. Among these the Godaveri Delta system paid 19.17 and the Kistna Delta system 16.00%; both are in Madras. In the United Provinces

the Ganges Canal gave 8.35%; and in the Punjab the new Chenab Canal gave 18.88% and the old Bari Doab Canal paid 11.50% on their respective capital sums. But, important as these financial results are, they are of little importance compared with the material benefit which the people derive from the irrigation. Among the 13 works which are mentioned above as unremunerative, there is more than one which, in a year of drought, has been the means of saving the people from distress, and, of placing in their hands grain equal in value to at least half the capital cost of the canal, which, judged by the hard test of commercial result to the Government, has to be classed as the unremunerative. The capital cost of the "Productive" and "Protective" works in operation was 384 728 087 rupees in 1902, the value of the crops irrigated by them was estimated at 362 214 130 rupees, or nearly the same as the capital outlay. A large proportion of these same crops would have been raised, in that year, on the same ground, had the canals not existed, although the out-turn would not have been as good. But in a year of drought the case is very different. Then, a particular canal commanding a tract which is severely affected may really save its entire capital cost in one year. The gross area irrigated in 1901-02 by the irrigation works controlled by the State was 19 916 567 acres.

These facts are now fully recognised in India, and one of the instructions to the Commission, which lately investigated the irrigation question, was that, in considering proposals for new irrigation works, the Commission should understand that greater importance may often be attached to the extent and reliability of the protection that will be afforded, than to the merits of the schemes regarded as financial investments. The irrigation works hitherto constructed by the State in India have, on the whole, proved directly remunerative; but it is recognized that the programme of works of this kind may be approaching completion, and that the great storage works required for any considerable extension of irrigation, in the tracts which are most exposed to famine, must, necessarily, be more costly per acre protected, and therefore less remunerative, than the completed works which draw unfailing and perennial supplies from the great rivers in Northern and Southern India. The Commission has recommended the expenditure of 440 000 000 rupees—say £30 000 000—on projects which are estimated to irrigate 6 500 000

acres, chiefly in Madras and the Punjab. Only a portion of this capital is proposed to be expended on works which will pay more than 5%, and the Commission contemplate that the net financial result of their proposals will be an annual charge of about half a million sterling on the revenues of India.

The protection against famine which is afforded by irrigation works is often exaggerated. The enthusiastic philanthropist writes as though the expenditure of sufficient money on irrigation would effectually prevent all famines. This is not so. It may be safely said that failure of crops from want of moisture will always occur, at intervals, in parts of the Indian continent. It is true that irrigation works, in a particular district which is liable to famine, will not only relieve from want the tract which is actually irrigated, but will relieve the distress of a zone lying for some distance beyond the borders of the tract. But, since irrigation is physically impossible in all the tracts which may be visited by famine, it is not possible to protect all afflicted areas. In those areas where irrigation cannot be practiced the importation of grain is the only means of affording relief to the people; and, of course, the more grain there is available, the nearer it is to the point where it is required, and the better the means of communication, the less difficult it becomes to feed the people. There never was a time when, taking India as a whole, the food supply of the continent was insufficient to sustain the population. The difficulty has always been to organise the administration, to establish the means for apportioning and distributing the relief, and to deliver the grain to the people without demoralizing the population and without unreasonable cost to the State.

TABLE 1.

Province.	Probable area of food grains insured by the canals. Acres.	Population supplied with food for one year by the works.	Population of the province.
Bengal	650 000	1 700 000	74 700 000
United Provinces	3 000 000	7 500 000	47 700 000
Punjab	5 000 000	12 500 000	22 500 000
Madras	5 000 000	12 500 000	38 200 000
Bombay and Sind	3 000 000	7 500 000	18 500 000

It is not easy to measure, with accuracy, the degree of protection from famine which is afforded by the State Irrigation Works of India. An acre of food grains will feed from 2½ to 3 people for a year. Table 1 gives an idea of the probable facts in the five principal provinces.

The food of about one-fifth of the population in these provinces is, therefore, assured by the irrigation works. But, actually, the measure of protection is greater, as portions of the provinces, notably in Bengal, are naturally protected from any fear of famine.

The British engineers who have done much, and hope to do much more, to extend irrigation works in India, look with some pride on the fact that their works are successful financially and economically. The rulers of India regard these works, perhaps, somewhat from a different point of view. They see in them not only a profitable property, a sound financial investment, but, far better, an active force ever potent to tie the population to their rulers, to render them happy in their homesteads and contented with their surroundings; a condition which cannot but tend to political advantage and security. The Swat River Canal on the borders of the Punjab has probably done more in ten years to still the turbulence of a quarrelsome frontier tribe than all the police of the Province could have done in half a century. The Chenab Canal, which has provided new and prosperous homes to more than a million inhabitants, has done in half a century. The Chenab Canal, which has provided of British rule than the Queen's Proclamation of 1858 and than all the resolutions of the Government since Queen Victoria assumed sovereignty of the country.

Egypt.

*In Egypt there are two distinct systems of irrigation employed, namely, the basin system and the system of perennial irrigation. The basin system is irrigation by inundation during the period of the Nile flood; perennial irrigation is the ordinary continuous irrigation by field channels throughout the year. The basin system has survived in Upper and Middle Egypt, but in Lower Egypt perennial irrigation has taken its place. As the terms are used in this paper, Upper Egypt includes the Nile Valley from Assuan

*W. W. (1), Chapters III and IV.

to Assiout, about 1 million acres of cultivated lands; and Middle Egypt, the valley from Assiout to Cairo, inclusive of the Fayum, about 1½ million acres; Lower Egypt embraces the whole of Egypt north of Cairo, that is, the Delta, 3½ million acres.

*The basin system is very ancient, perhaps as old as Egypt itself. Its early history is associated with Lake Moeris (about 2500 B. C.). Under the basin system, the natural inundation, caused by the Nile overflow, is assisted by longitudinal and transverse banks enclosing the lands to be flooded in such a way that the water is ponded up in each basin to the extent required to make it cover the higher lands as well as the lower. In 1884, the year when British engineers took over the direction of irrigation in Egypt, some of these banks were found to have masonry regulators and escapes in them to admit of the water being retained or passed on at will, but the works were more or less ruins, the controlling apparatus was very imperfect or altogether wanting, and the waterway provided absolutely inadequate. Consequently, when the time came for running the water off in order that the crops might be sown, the discharge of the basins had to be effected mainly by cutting the earthen banks, a practice that was objectionable, not only on account of the subsequent expense of closing the cut to prepare for the next flood, but also because, the cut once made, all control over the water was lost, as it was impossible to close the cut until the water had run off.

The inundation of the basins was facilitated by canals carried through the high lands bordering the river. These canals had rarely been provided with head-works of control, and, as a rule, did not take off from the river at a point far enough upstream from the lands depending on them, to be efficient during a flood of low levels. †The defects in the Upper Egypt basin system became evident during the low flood of 1888, and their effect upon the revenue, whilst Egypt was still struggling with penury, acted with such persuasive force on those responsible for the finances of Egypt that the demand for a special grant of about three quarters of a million pounds to put things right was acceded to. The late Colonel J. C. Ross, when Inspector General of Irrigation, made this work of remodelling the Upper Egypt basin system his own peculiar care.

* R. H. B. (1).
† E. P. W. (1), 1888.

*No single work among those executed was of great magnitude, but the scheme, as a whole, was of considerable importance, a sum of £800 000 being spent in carrying it out. †Since this remodelling work was done, the utility of it has been tested by the extremely low flood of 1899, which was a flood similar to that of 1877, but a decidedly lower one than that of 1888. The following figures, which include Middle and Lower Egypt areas, show the improvement:

Year of low Nile flood.	Area left without inundation on which land tax was remitted.
1877	754 000 acres.
1888	366 000 "
1899	300 000 "

‡The chain of basins in Middle Egypt on the west of the river suffered, generally speaking, under the same defects as those of Upper Egypt, but a complication had been introduced by the Khedive Ismail Pasha when, about the year 1870, he acquired a large estate forming a band of 2 to 6 miles in width alongside of and parallel to the river. In order to cultivate sugar-cane in these lands, he protected them from inundation on the side of the basins by a longitudinal bank, and dug a canal from Assiout throughout the whole length of the estate for its perennial irrigation. This canal, called the Ibrahimia, together with the enclosed strip of land, cut off the remaining portions of the basins from the Nile, so that, thereafter, all the inundation water they received had to leave the river at Assiout, or at some point above it, and be passed on through 125 miles of the Nile Valley. The basins at the lower end of the chain suffered in consequence from the loss of the rich deposit which its direct Nile feeders used formerly to give in high floods. On the other hand the land was more secure in a low flood, as the new Ibrahimia Canal contributed a better supply with low river levels than the shorter direct feeders used to give. But the gain of better security in low floods was not so great a gain if the lands must be impoverished to obtain it. The obvious reform, therefore, called for in Middle Egypt was the restoration of the direct flood feeders by digging canals from favourable points on the river, passing

*J. C. R.
†E. P. W. (1), 1899.
‡R. H. B. (2).

them in syphon under the Ibrahimia Canal and tailing them into the basins. *In addition, as in Upper Egypt, banks had to be remodelled and efficient regulators provided. Of the new regulating works built, the most important was the Kosheshah Escape. †This Escape, which is at the tail of the Middle Egypt chain of basins, has to discharge in 20 days the inundation water of over half a million acres, calculated to amount to 2 600 million cu. yd. The Escape is constructed with upper and lower sluices, and has 60 double-storied bays of 9 ft. 10 in. (3 m.) width. The lower sluices are fitted with direct-lifted gates sliding in vertical grooves and operated by an overhead winch. The upper sluices are furnished with horizontally-pivoted falling gates arranged for quick opening when the time comes for letting the water off to empty the basins. The lower sluices are used for allowing water to flow into the basin direct from the Nile when the levels permit, and also for regulating the water level in the basin by opening or closing them as may be found necessary, and for draining off the water from the low-lying parts of the basin. Before the construction of this Escape the discharge of the Middle Egypt chain of basins was effected by annually making a cut in an earthen bank.

But more need not be said of the basin system of irrigation, as it is doomed to disappear and to give place to perennial irrigation which produces two crops a year instead of one, and more than doubles the value of the land. ‡Already in Middle Egypt the greater part of the basins have been converted from the old to the new system as a consequence of the construction of the Assuan Dam. The summer supply is, therefore, the problem of the future, and is, on that account, the better worth study.

§Modern methods of irrigation and cotton cultivation were first introduced into Egypt by Mehemet Ali, Viceroy of Egypt, in the beginning of the nineteenth century. He and his successors abolished the corn-growing basin system in the Delta and replaced it by perennial irrigation, a change necessitating the protection of the cotton-cropped lands from inundation, by Nile banks on both branches of the river, and an adequate supply of water all the year

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* E. P. W. (1), 1890, p. 50.
† R. H. B. (2); E. P. W. (1), 1891, p. 98.
‡ E. P. W. (1), 1902, p. 114.
§ W. W. (1), Chapters V and VI.

round in canals within reach of the crops. *To give the continuous supply of water, the Delta Barrage was designed and built by an able French engineer, Monsieur Mougel. This important work was intended to divert the summer water of the river at its bifurcation from its natural channels, known as the Rosetta and Damietta Branches, into the artificial canals made or utilized for the perennial irrigation of the Delta.

The Barrage consists of two large regulating works, one across the head of each branch of the Nile, situate about 15 miles north of Cairo. Until the year 1884, this work had been treated as a failure, and was reckoned by most residents in Egypt, engineers or otherwise, to be a hopeless failure. It was designed to hold up 14 ft. 9 in. ($4\frac{1}{2}$ m.) of water on both branches; it had only succeeded in holding up as a maximum 5 ft. 9 in. ($1\frac{3}{4}$ m.) on the Rosetta Branch and nothing at all on the Damietta Branch. In 1867, a length of the work, including several bays toward the west end, had shown unmistakable signs of failing, and this portion had to be enclosed in a coffer-dam to save it from ruin. The digging of the main canals, taking off from above the Barrage, was arrested, in consequence, before the main eastern canal had been commenced. †In the Egyptian Public Works Report for 1883, the Barrage was officially condemned as unfit to serve the purpose for which it was designed, and the retiring Director General of Public Works recommended the construction of large pumping stations as a substitute for it.

In May of that same year (1883), Colonel (now Sir) Colin Scott Moncrieff, an irrigation engineer of wide experience in India, was given charge of the irrigation in Egypt. Within twelve months there arrived in Egypt, to serve under Sir Colin, four other engineers of the Indian Irrigation Service, to whom a fifth was added at the end of 1885. ‡These six men were the pioneers of reform in the administration of the Irrigation Service of Egypt. In 1884 Sir Colin obtained full control of the Irrigation Department, and at once set his lieutenants to work to get things straight. From that time the record has been one of uninterrupted progress and increasing prosperity in the country.

*S. M. (1) and (2); W. W. (1), Chapter IX; R. H. B. (3).
†S. M. (1), p. 4; S. M. (2), Lecture II.
‡A. M., p. 289.

The problems before Sir Colin and his staff were the following:

1.—To perfect the means of making the whole discharge of the river in summer available for irrigation;

2.—To secure an economical and just distribution of the water;

3.—To provide drainage facilities to carry off excess water in the flood and winter seasons;

4.—To afford security from inundation in the flood seasons.

The first problem, *viz.*, the utilization of the whole summer discharge of the river, was solved by making the Delta Barrage absolutely efficient.

*The repair work necessary to enable it to hold up 13 ft. (4 m.) head of water was carried out by the late Mr. A. G. W. Reid under Colonel Western's direction. The restoration was effected in four seasons on half of each regulator at a time, the part of the work to be operated on being surrounded by banks and laid dry by pumping. The old defective floor was then extended up and down stream, and built upon to the extent required by the conditions in which the work was found when unwatered; and both regulators were fitted throughout with gates of simple construction sliding in vertical grooves and manipulated by overhead winches. This restoration work was entirely successful and the Barrage at length held up 13 ft.

†The foundations were afterwards further consolidated by forcing cement grout, under the pressure of its own weight in bores 50 ft. high, into and under the defective bottom layers of the floor. The bores, by which the cement grout was introduced, were made in the thickness of the masonry piers from roadway level, five bores being so made in the length of each pier. The evidence obtained of the result of the work was considered to justify the opinion that the operations had added materially to the stability of the structure.

‡The efficiency of the Barrage was subsequently still further increased by the construction of weirs at a short distance downstream. The weirs hold up, at lowest water, 10 ft. 8 in. ($3\frac{1}{4}$ m.), and the barrage may be called upon to hold up another 9 ft. 9 in. (3 m.) only, so that, while the possible heading up has been increased

*R. H. B. (3), Chapter III; E. P. W., 1886 to 1890; W. W. (1), Chapter IX; S. M. (1); S. M. (2), Lecture II.

†R. H. B. (3), Chapter IV; R. H. B. (4); E. P. W., 1896 to 1898.

‡R. H. B. (3), Chapter V; E. P. W., 1898 to 1901.

by the action of the weirs from 13 ft. to 20 ft. 5 in. (4 to 6¼m.), the Barrage itself is required to hold up only 9 ft. 9 in. instead of 13 ft. *The weir core and footing walls below water level, as also the foundations of the associated locks, were put in successfully under water by the employment of cement grout. A movable timber caisson was employed to contain the rubble and grout up to water level until the setting of the cement had formed the contents into solid masonry blocks. Under this system of construction, pumping, plant and skilled labour were almost entirely dispensed with. The resulting weirs have been pronounced to be the tightest in existence. The construction of these works furnishes a remarkable instance of the use of cement grout on an extensive scale for subaqueous foundations.

The combination of barrage and weirs is now such an efficient one that every drop of water, flowing down the river in summer, is forced into the irrigation canals and carried to the fields, and the first rise of the floods is taken full advantage of. The Barrage gates are even caulked with rags to prevent any loss by leakage until the maximum head of 6¼ m. is held up and the gates are topped.

†The second problem stated above, namely, to secure an economical and just distribution of the water, was as important as the first. The question was one of administration rather than of construction. Hitherto the rich had been given or had taken what water they wanted, and the poor had to content themselves with the crumbs that fell from the rich man's table. This problem was solved in a manner new to Egypt, mainly by an impartial and rigid application of a well-considered rotation programme, whereby both justice and economy were secured in times of water scarcity. Under this system the canals are formed into different groups, and each group, in its turn, is supplied with water and deprived of it at other times. In this way, a high "duty" has been got out of the water. ‡After many observations and calculations, the conclusion has been arrived at that the allowance of water for cotton should be 1 000 cu. ft. per diem per acre of crop, and for rice double that amount. These allowances are those which should be supplied

*R. H. B. (4).
†E. P. W. (1), 1902, pp. 155 and 156.
‡E. P. W. (1), 1902, pp. 166 to 170.

at the head of the main canal, as provision is thereby made for loss during flow between the source of supply and the field to be irrigated.

To enable the rotation system to be efficiently applied, it was necessary to have adequate control over distribution. To obtain this a very large number of existing regulating works of all descriptions were repaired, if not too far advanced in decay, and many new ones were built. *The scheme of main and branch canals was also developed. The irrigation machinery for controlling the water grew annually in perfection to the extent that funds allowed.

†An improvement in working the canals was made by introducing dredging to clear the main canals. Formerly, in order to clear them by hand, they had to be closed, often when water was wanted, the labourers employed being unpaid and unfed and beaten, under the Corvée system. ‡The Corvée that used to execute the annual earthwork of canal clearances and bank repairs has now been entirely abolished; the work is paid for, and it is better done than before, being controlled by capable engineers instead of by ignorant taskmasters with "kourbashes." The abolition of the Corvée was rendered possible by the great economy in clearances resulting from the restoration of the Barrage to efficiency, and this economy will be still more pronounced now that the weirs have further added to the power of regulating the river levels. §The work done previously by the Corvée is now carried out for £400 000. The abolition of the unpaid labour system dates from 1889. **Previous to 1884 the numbers employed were estimated to be 125 000 men working for 150 days, and in 1884, 92 609 men for 130 days.

††At the same time that the canal system was being perfected, an extensive scheme of drains was carried out at a cost of over one million pounds.

‡‡Protection from flood was also afforded by giving the Nile bank such dimensions as would guarantee security, by retiring unsafe lengths and by guarding against river encroachments with stone spurs and revetments where erosion created danger.

*S. M. (1), p. 11.
†E. P. W. (1), 1886, p. 9; 1887, p. 7; 1888, p. 9.
‡W. W. (1), Chapter XIII; S. M. (3).
§E. P. W. (1), 1889, p. 49; 1890, p. 47.
**E. P. W. (1) 1884, p. 21.
††E. P. W. (1), 1897, p. 139, and map at end.
‡‡W. W. (1), Chapter X; E. P. W. (1), 1896, p. 150.

*By such means, operating since 1884, the cotton crop has been increased from 3 million to 6 million cwt. in round figures, or in value from £7 500 000 to £15 000 000; the timely sowing of the maize crop has been made a certainty; the expense of raising crops has been lessened with the diminution of height through which the water has to be raised for irrigation; †the Corvée and its attendant abuses have been abolished; the cultivable area of Egypt has been increased from 5 to 6 million acres; the value of land has been doubled, and a feeling of confidence in the Irrigation Service has been established. ‡And meanwhile, as these benefits were accruing, the land tax was reduced from 5 to 4½ million pounds in round figures.

The expenditure incurred in bringing about these results was made up approximately as follows:

Annual budget allotment for ordinary maintenance and administration	£620 000
Special expenditure not charged against the annual budget allotment:	
Delta Barrage restoration and weirs	£900 000
Development of Delta Canals	800 000
Drainage	1 000 000
Remodelling Upper Egypt Basin system	800 000
" Middle Egypt Basin system	300 000
	£3 800 000

§But the limit of expansion was reached in the summer of 1900. Every drop of water that was to be got out of the river was utilized for the irrigation of the cotton crop, and each drop was made to do the maximum of work possible. Any considerable further increase of cultivation was not to be expected without adding to the available summer supply.

* R. H. B. (3), Chapter VI.
† E. P. W. (2), p. 5; W. W. (4), p. 4.
‡ W. W. (1), p. 386.
§ E. P. W. (1), 1900, pp. 7, 72 and 131.

*So the question of reservoirs for the storage of water had come to the front; and, after four years' study by Sir William Willcocks, the construction of the Assuan Dam was decided on, and actually commenced in 1898. †Also, in order the better to distribute the increased water supply thus to be obtained, the Assiout and Zifta Barrages were undertaken while the Assuan Dam was building. These three magnificent additions to Egypt's irrigation works were all built during the five years succeeding the signing of the contract for the Assuan Dam and the Assiout Barrage in February, 1898.

‡The Assuan Dam is built on the granite rock which forms the crest of the First Cataract, 600 miles to the south of Cairo. The original design of the dam was the work of Sir William Willcocks; the dam, as actually built, was in principle the same as that originally designed, but was modified in details. It is about 1¼ miles (2 000 m.) in length. Its height varies with the level at which sound rock was found, the maximum height from foundation being about 125 ft. (37 m.). The thickness of the dam at the top is 23 ft. (7 m.) and at the deepest part 81 ft. (25 m.), and the total weight of masonry in it is over one million tons. The difference of water level above and below the dam is 67 ft. (21 m.). The dam is constructed of local granite set in Portland Cement mortar. The interior is of rubble laid by hand, with about 40% of the bulk in cement mortar, 4 of sand to 1 of cement. All the face work is of coursed rock-faced ashlar, except the sluice linings, which are finely dressed. The lining of 30 of the lower sluices is of cast iron. The dam is pierced with sluice openings of sufficient area to pass the flood discharge of the river, which may amount to 500 000 cu. ft. per sec. There are 140 such openings 23 ft. (7 m.) high by 6 ft. 6 in. (2 m.) wide, and 40 more of half that height and same width. Those sluice-gates which are subject to heavy pressure at the time of movement, are of the Stoney roller pattern. Navigation is provided for by a ladder of four locks, each 263 ft. (80 m.) long by 31 ft. (9½ m.) wide. The cost of the dam was 2½ million pounds.

The reservoir above the dam, as built, is calculated to hold about 1 300 million cu. yd. of water with the water surface at 106 m.

*E. P. W. (2).
† E. P. W. (1), 1898 to 1902.
‡ B. B. F. & S.

above sea. It had originally been decided to build the dam 26 ft. higher, so as to hold up water to 114 m. above sea, which would have given a storage capacity in the reservoir of 3 250 million cu. yd. But the Egyptian Government gave way before the strong protests against the submersion of Philæ raised by archæologists and artists, and the lesser project was adopted; a compromise which is far from satisfying the champions either of the past or of the present. After the first year's working of the reservoir, Egypt is as thirsty as ever and crying out for more water.

The Assiout and Zifta Barrages do not store water, but distribute the available supply by producing artificial levels in the river convenient for feeding the canals depending on them. In design they are similar to the first Barrage below Cairo; but the Assiout Barrage spans the whole undivided river, and the Zifta Barrage one of the Delta Branches only. The duty of the Assiout Barrage is to feed the Ibrahimia Canal, which irrigates the sugar-cane and cotton plantations of Middle Egypt. The Zifta Barrage, on the Damietta Branch, facilitates the distribution of water in Lower Egypt by feeding the Long Eastern Delta canals—some of which are more than 100 miles in length—at a fresh point about half way between the old Barrage and the sea. *Both the Assiout and Zifta Barrages are built on platforms, 9 ft. 9 in. (3 m.) thick and from 85 to 100 ft. (26 to 30 m.) wide, enclosed between up- and down-stream rows of cast-iron piles specially designed to permit of the junctions being grouted with cement. In addition, there are apron extensions to the floor, the up-stream apron being of rubble and puddled clay, the down-stream apron of rubble overlying a filter bed of pebbles and fine stuff. The Assiout Barrage is 900 yd. in length and has 111 bays of 16 ft. 5 in. (5 m.) width, separated by piers 6 ft. 6 in. (2 m.) wide, with abutment piers of 13 ft. (4 m.) thickness after every ninth opening, and a lock of 52 ft. 6 in. (16 m.) width and 263 ft. (80 m.) length. Two iron regulating gates, as in the old Barrage, are worked in vertical grooves by an overhead winch, and provide for holding up a level of 9 ft. 9 in. (3 m.) of water. The Zifta Barrage has 50 bays, but is in other respects similar to the Assiout Barrage, except that it is designed to hold up 13 ft. of water.

*G. H. S.

The cost of these three works, and works in connection with them, is given approximately by the following figures:

Assuan Dam	£2 500 000
Assiout Barrage and Works	1 000 000
Zifta Barrage and Works	500 000
Conversion of 451 000 acres from basin to perennial irrigation	3 000 000
Total	£7 000 000

The 1 300 million cu. yd. of water, annually stored in the Assuan Reservoir, whether used for conferring perennial irrigation to basin lands, or for the reclamation of land hitherto uncultivated, may be considered to be worth £3 750 000. For, in consequence of such a supply, the annual rent of 1 250 000 acres will rise by at least £3 an acre. *The value of the cotton crop raised annually by it may be estimated as worth from 4 to 5 million pounds. Government will gain directly in land tax £625 000, and indirectly much more; the land owners will gain in increased rentals, less the increase on land tax, £3 125 000; and the sale value of their land will increase by £30 an acre, or in all £37 500 000.

Future Developments.

†In spite of all that has been accomplished, much more remains to be done before Egypt is content and the Soudan developed, or the utilization of the Nile water is complete. It has been estimated that Egypt alone still requires in summer, in addition to the 1 300 million cu. yd. of water stored in the Assuan Reservoir, 4 to 5 000 million more for its complete development. What the Soudan requires as its summer supply has not yet been put into figures.

Sir William Garstin's expeditions to the Nyanza Lakes and the region of the "Sadds" above Khartoum, and Mr. C. E. Dupuis' expedition to Lake Tana, have made it more profitable than it was before to discuss comprehensive projects for the further control of the Nile, and to estimate the value of suggestions made from time to time on less reliable data than are now available.‡

* Eg. No. 1 (1904), p. 23.
† Eg. No. 2 (1901).
‡ W. W. (3).

The problem to be solved is that of the storage of the water which now finds its way to the sea during the flood and winter seasons, in order that it may be reserved for use in summer when it is wanted. There is a second problem, namely, that of preventing the loss of water which takes place by evaporation and absorption in the extensive swamps between Khartoum and Gondokoro.

What first suggests itself to anyone giving his mind to the subject is that the Lake Victoria Nyanza would form an ideal reservoir on account of its extensive surface area of 26 000 sq. miles. It would be so easy and cost so little to make a weir at the Ripon Falls—the point where the lake discharges into the river—sufficiently high to store in the lake enough water to meet the needs of Egypt and the Soudan. But with the weir constructed, how is the reservoir to be filled? *The catchment area, beyond the limits of the lake itself, is approximately only three times the area of the lake. Evaporation and absorption disposes of nine-tenths of the rainfall, and the balance only finds its way to the Nile over the Ripon Falls. The relation of the lake area to the catchment area and the rainfall disqualifies the lake for service as an efficient storage reservoir. The very size of the lake, which was thought a recommendation, is the reverse.

This conclusion being accepted, the next thing that suggests itself is to make the Albert Nyanza Lake the reservoir, its area being one-fourteenth that of the Victoria Lake, and its catchment area, which includes that of the larger lake, being more extensive. One metre depth over the area of the Albert Lake represents a storage capacity of 6 500 million cu. yd. In the case of this lake, also, evaporation and absorption are important factors to be reckoned with, and the rainfall and catchment area may not be sufficient to give a satisfactory balance after deduction of the loss due to those neutralizing factors.

There is a further objection to either of the lakes as a storage reservoir. The water supplied by a reservoir in such a situation would have to pass through the region of the "Sadds," and would spread itself abroad over these vast swamps and be dissipated; so that what evaporation and absorption had left to flow out of the reservoir would be swallowed up by evaporation and absorption

*R. B. B. (1).

in the Soudan marshes, and an insignificant remnant only would survive to reach Khartoum.

Under present conditions of the river, more than half of the total amount of water issuing from the lakes is lost in the marshes. Sir W. Garstin has estimated that it would cost nearly four million pounds to create an embanked channel of sufficient capacity to carry the river discharge through the 400 miles of marsh. It would be easy to show by figures that such an expenditure would be well worth incurring if, by so doing, the loss due to the spreading out in the marshes is prevented, and the summer discharge at Khartoum of about 33 million cu. yd. a day, is thereby doubled. An addition of 33 million, continued for the 80 days of summer when the increase is required, would represent 2 640 million cu. yd. of water, or double the quantity stored by the Assuan Reservoir.

*Sir William Willcocks advocates raising the Assuan Dam by 20 ft. and thereby doubling the storage capacity of the reservoir. He also recommends connecting the Wady Rayan with the Nile and using it in conjunction with the Assuan Reservoirs. The Rayan Reservoir would act in a similar way to the ancient Lake Moeris, and could be made to store two or even three millions† of cubic metres of water above the level to which its contents could be utilized for supplementing the summer Nile. The Wady Rayan is a depression in the desert alongside the Fayum, which it resembles, in that its lowest point descends to more than 40 m. below sea level. About 20 years ago, attention was called to the possibility of making the depression into a storage reservoir by Mr. Cope Whitehouse, an American visitor to Egypt of several winters.

It is also possible to make other reservoirs in the trough of the Nile itself by the construction of dams similar to the Assuan Dam on one or more of the cataracts between Assuan and Khartoum. So that Egypt has a choice to make from several practicable proposals, and, now that the Anglo-French agreement gives the Egyptian Government liberty to dispose of accumulated funds in hand, it will doubtless make its choice and get to work on the selected project.

For the irrigation of that part of the Soudan which lies on the right bank of the Nile about Khartoum, including the Island of

* W. W. (3); W. W. (4); R. H. B. (1), Chapter V.
† The word "millions," as here given, should read "milliards."

Meroe, the Blue Nile water will doubtless be utilized. It has been suggested that a storage reservoir might be made of the Abyssinian Lake Tana which has a surface area of 1 300 sq. miles. Here again the relation between the lake area on the one hand, and the catchment area and rainfall on the other, appears to be such that the discharge obtainable from the lake in summer cannot be made great enough to meet requirements. The summer discharge of the Blue Nile falls to less than 200 million cu. ft. a day, and, unaided, could not be relied upon for the irrigation of a crop of any considerable area requiring water during the months of lowest discharge. But if Egypt and that part of the Soudan which could utilize the water of the White Nile were to have their irrigation fully provided for by a combination of the alternative projects named before, the Blue Nile summer water (whatever it may amount to), supplemented by contributions from the Tana Reservoir, might be reserved for the lands on both sides of that river, and a considerable area of summer crop be thereby raised on them. What that possible area may be can be calculated better after Mr. Dupuis' report is made public. But assuming that a summer discharge of 700 million cu. ft. a day is, with the help of a Tana Lake Reservoir, made available for irrigation from the Blue Nile, an area of 700 000 acres of summer crop could be raised by utilizing the whole discharge; or, assuming that two-fifths of the whole area brought into cultivation is under summer crops, the area that could be given perennial irrigation would be 1 750 000 acres.

To distribute the water, barrages on the Blue Nile at the most favourable points, with a system of canals in connection with them, would, of course, be necessary.

Another way of solving the difficult problem of Soudan development, under the present conditions of the summer supply which is all claimed by Egypt, is to produce, by methods of evolution known to expert horticulturists, a variety of cotton that will come to maturity if sown in June, that is, after the Blue Nile begins to rise, when there is water enough and to spare.

The soil of the Soudan is only waiting for the water of life for the seed to bear its "hundredfold." The "Isle of Meroe" alone, lying between the Blue Nile and the Atbara is an extensive waste of good soil, such as that to which the Chenab Canal in India has

given life. It is water that is wanting, and to find it is the present-day Soudan question, as twenty years ago irrigation was the Egyptian question. Those same twenty years have done much for Egypt. In 1884 the value of landed property in Egypt was roughly 120 million pounds, made up of 2 million acres of basin land at £15 an acre and 3 million perennially irrigated lands at £30. *To-day the value has increased to 275 million pounds, made up of 2 million acres at £25 an acre and 4 million at £55. If the Soudan question can be answered as satisfactorily, it will be well with the Soudan.

* W. W. (4), p. 4.

APPENDIX.

Publications Issued Since 1883.

Abbreviation used in this Paper.	Author.	Title of Work.	Publisher.
B. B.	Benjamin Baker	Lecture. Royal Institution. The Nile Dams and Reservoirs	Bedford Press.
R. H. B. (1)	R. H. Brown	The Fayum and Lake Moeris	E. Stanford.
R. H. B. (2)	" "	Paper on Kosheshah Basin Escape	R. E. Inst., 1892, Vol. XVIII.
R. H. B. (3)	" "	The Delta Barrage	Public Works, Egypt.
R. H. B. (4)	" "	Paper on the Use of Cement Grout at the Delta Barrage	Inst. C. E., 1904.
R. B. B. (1)	R. B. Buckley	Paper, Colonization and Irrigation in E. Africa Protectorate	R. Geogrl. Journal, April, 1903.
R. B. B. (2)	" "	Irrigation Works in India	E. & F. N. Spon.
Eg. No. 1 (1904)	Lord Cromer	Egypt and the Soudan in 1903	Eyre and Spottiswoode.
Eg. No. 2 (1901)	Cromer and Garstin	Egypt No. 2 (1901)	Harrison & Sons.
F. & S.	Fitzmaurice and Stokes	Papers on Nile Reservoir and Sluices, Assuan	Inst. C. E., 1903.
W. G.	W. E. Garstin	Irrigation Projects on Upper Nile. Egypt No. 2 (1901)	Spottiswoode.
A. M.	A. Milner	England in Egypt	E. Arnold.
E. P. W. (1)	Public Works, Egypt	Annual Irrigation Report 1884 to 1902	Public Works, Egypt.
E. P. W. (2)	" "	Perennial Irrigation, etc	Public Works, Egypt.
J. C. R.	J. C. Ross	Notes on Distribution of Water, etc	Public Works, Egypt.
S. M. (1)	Scott Moncrieff	Notes on Nile Barrage	Public Works, Egypt.
S. M. (2)	" "	Irrigation in Egypt (3 lectures)	R. E. Inst., 1893, Vol. XIX.
S. M. (3)	" "	Note on the Corvée in Egypt	Public Works, Egypt.
S. M. (4)	Scott Moncrieff and Commission	Report of Indian Irrigation Commission	Eyre and Spottiswoode.
G. H. S.	G. H. Stephens	Paper. The Barrage Across the Nile at Assiout	Inst. C. E., 1904.
W. W. (1)	W. Willcocks	Egyptian Irrigation (2d Edition)	E. & F. N. Spon.
W. W. (2)	" "	Paper. Irrigation in Lower Egypt	Inst. C. E., 1887.
W. W. (3)	" "	The Nile Reservoir Dam at Assuan and after	E. & F. N. Spon.
W. W. (4)	" "	The Assuan Reservoir and Lake Moeris (Lecture)	" "

TRANSACTIONS

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

Paper No. 32.

IRRIGATION.

IRRIGATION IN JAVA.

By J. E. de Meyier.*

I. General View of the Country.

For the American reader, the Island of Java is no longer an unknown country, since Professor Clive Day has given such an able and interesting account of its political history,† and it is an attractive task to complete that knowledge with a glance at its natural and agricultural conditions.

Situated in the tropical zone, between 6 and 9° south latitude and extending in length from west to east over 660 miles, while the breadth of the island does not surpass a fifth of that measure, Java is peculiarly under the influence of the sea and the regular monsoons which are observed in this portion of the Indian Archipelago. A series of volcanoes forms the tops of the mountain range which constitutes the backbone of the island, and it is in creeping up against the slope of these mountains, that the water-laden clouds

* Formerly Director of Public Works in Netherlands' India.

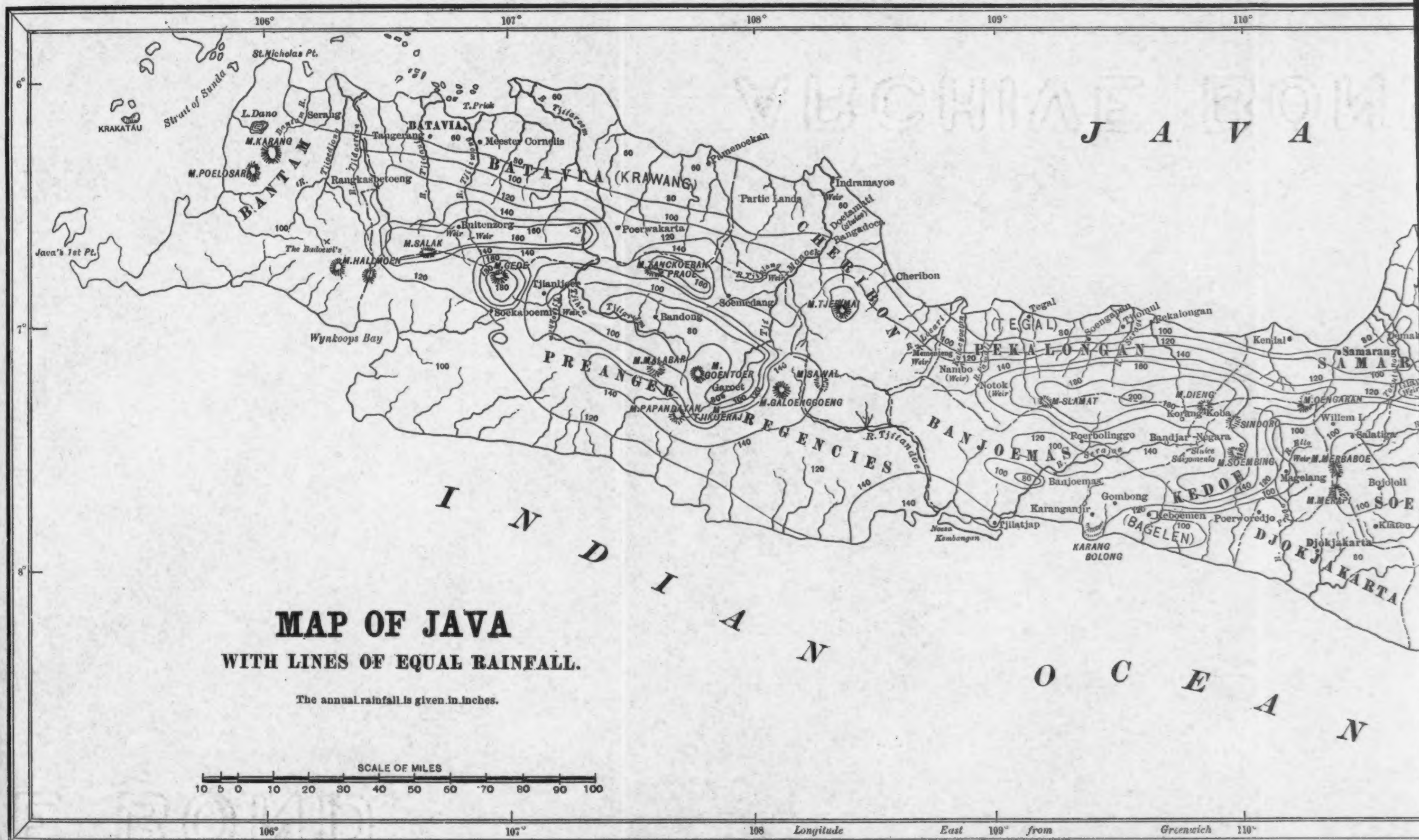
† "The Policy and Administration of the Dutch in Java," by Clive Day, Ph.D., Assistant Professor of Economic History in Yale University. New York, The Macmillan Company, 1904.

from the sea are condensed and contribute to the plentiful rainfall which causes the fertility of the island.

The highest peaks do not exceed 10 000 ft., and the snow limit is nowhere attained, so that there is not, as in Italy and Hindoostan, that regulating cause of water flow which is the distinctive feature of perennial streams. As the rivers, on the whole, flow transversely to the general direction of the island, their length is small. Heavy showers have a marked influence on the supply, and, also for this reason, the latter is very variable.

The soil of Java is generally of volcanic origin, and the tertiary formation is the oldest that appears at the surface. The rocks are easily eroded by the strong agents, sun, air and water, and the clay is carried downward to the valleys and to the seacoast, where fertile plains are formed. In the western part of the island, this clay, as a rule, is more compact and heavy, and requires considerable moistening before it can be plowed. In the eastern part, the soil seems to consist of a greater portion of the direct products of volcanic eruption; it is lighter and in some instances more fertile. The lands where clay and sand are properly mixed are called "tanah ladoe" and allow two crops in a single year, while the heavy clay, or "tanah lindjad," generally can bear only a single crop. The rivers in their upper courses carry pebbles of volcanic origin, generally designated as andesite. These pebbles, lower down, grow smaller by erosion and decomposition until in the lower courses only silt or sand is carried. In some places the fields are covered with sand or pebbles by occasional floods, but there are also considerable tracts where the rock comes to the surface like the peaks of an underlying hill range, the interstices of which have been silted up by alluvial deposits. From the mode of formation of the island, *viz.*, the volcanic upheaval of the central tertiary benches, the erosion of the rocks by meteorological influence, the eruption of volcanic products, and the deposition of the products of erosion and eruption, carried along by the rivers, in the valleys and plains, it is obvious that only these latter parts are fit for permanent agriculture.

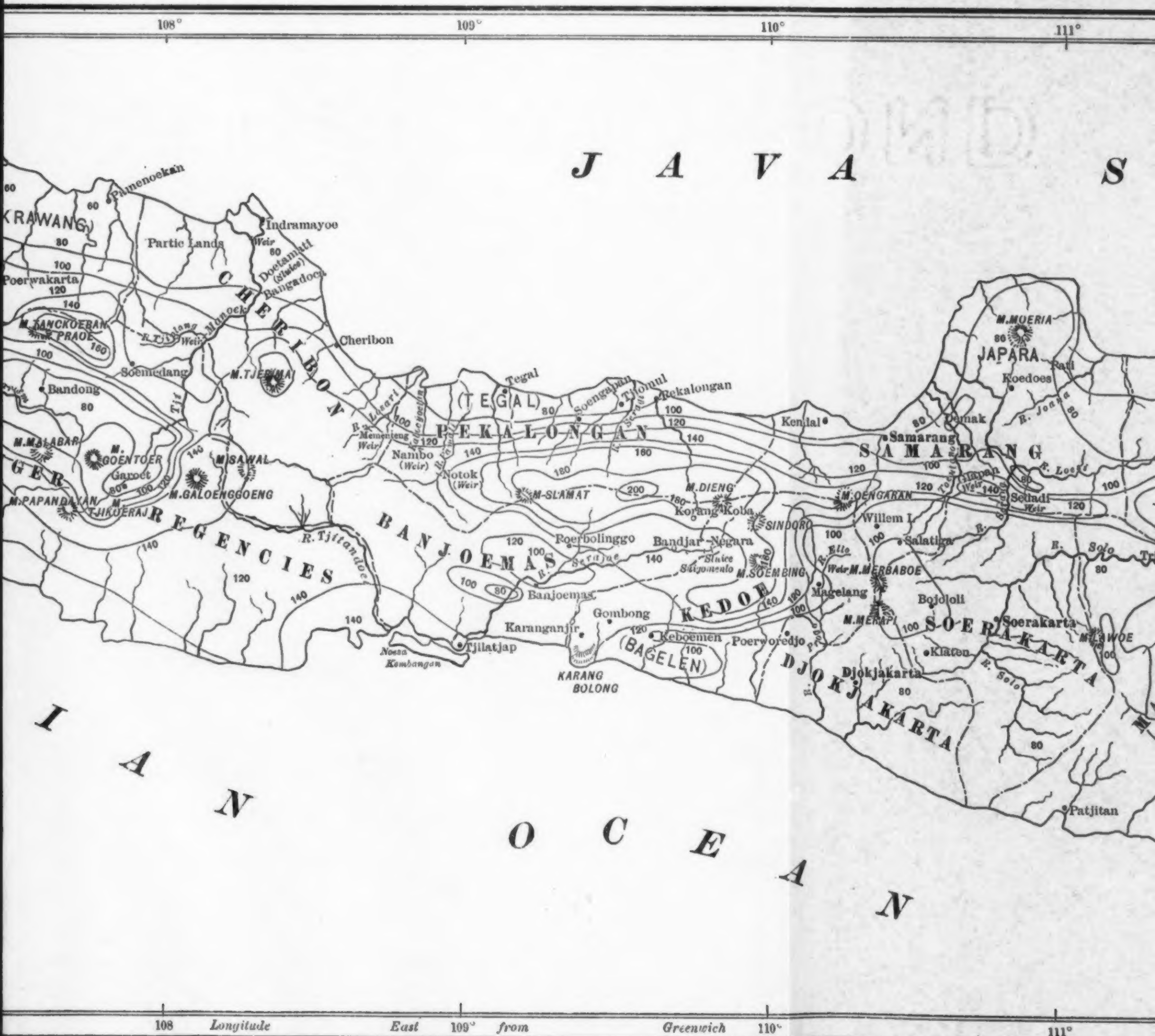
Everywhere, the slopes and steep ravines of the mountains are covered with a luxuriant vegetation, and only near the tops of the ever-active volcanoes, or where the hand of man has burned or



MAP OF JAVA

WITH LINES OF EQUAL RAINFALL.

The annual rainfall is given in inches.



108°
109°
110°
111°
J A V A S
I A N O C E A N
KRAWANG
Pamenoekan
Indramayoe
Partic Lands
Doetamati (Sluice)
Bangadoea
Poerwakarta
CHERIBON
M.TANGKOEBAN PRAOE
Cheribon
Soemedang
M.TJERIMAI
Bandong
M.MALABAR
M.GOENTOER
Garoet
M.SAWAL
M.GALOENGGOENG
M.PAPANDAJAN
TJIKOERAJ
REGENCIES
R.Tjitandoei
Tegal
(TEGAL)
Soengapan
Tjomul
Pekalongan
PEKALONGAN
Menenteng Weir
Nambo (Weir)
Notok (Weir)
M.SLAMAT
BANJOEMAS
Poerbolinggo
Banjoemas
Karanganjir
Gombong
Tjilatjap
Noesa Kembangan
KARANG BOLONG
M.DIENG
Korang Koba
SINDORO
Bandjar Negara
Sluice Singomerto
M.SOEMBING
KEDOE
Keboemen
(BAGELEN)
Poerworedjo
Magelang
DJOKJAKARTA
Djokjakarta
Kendal
Samarang
SAMARANG
M.OENGARAN
Willem I.
Salatiga
M.MERBABOE
M.MERAPI
Bojolali
SOERAKARTA
Soerakarta
Klaten
M.LAWOE
Patjitan
M.MOERIA
JAPARA
Koedoes
Pati
Demak
R. Joana
Sedadi
R. Solo
108 Longitude East 109° from Greenwich 110°
111°


S E A
REMBANG
Rembang
Toeban
Sidajoelawas
Oedjong Pangka
West Entrance
Bangkalan
MADOERA
Soemenep
Pamekassan
Low Land
Bengawandjezo
Grissé
Soerabaya
East Entrance
SOERABAYA
Bodjonegoro
Ngloewak
Trini
Ngawi
M.PANDAN
Melirip
Sidoardjo
MADOERA STRAIT
Modjokarto
Porrong Branch
Pasoeroean
Madioen
MADIOEN
Kertosono
Waroedjayeng
PATEGOEWAN WORKS
M.WELIRANG
M.ARDJOENO
M.WILLIS
Ponorogo
Kediri
KEDIRI
M.KELOED
M.KAWI
PASOEROEAN
M.BROMO
Probolinggo
Kraksaan
PROBOLINGGO
Besoeki
Sitoebondo
M.RINGGIT
Pekalen
M.BADERAN
M.ARGOPOERO
M.LAMONGAN
M.JANG
M.IDJEN
M.RAOEN
Blitar
Malang
Tosari
M.TENGGER
M.SMEROE
Alas
Petoeng
Loemadjong
Djember
BESOEKI
Banjoewangi
BALI.
Bali Strait
Poeger
POERWO
112°
113°
114°
6°
7°
8°

destroyed the forest, are there bare rocks and open spaces, the latter generally covered with a sort of indestructible long grass "alang alang" (*imperata arundicea*), which gives the greatest difficulty when such fields are to be brought under regular cultivation. The primitive inhabitants used to clear a space in the forest and sow a dry crop of rice on the spot; and when this so-called "hoema" or "tipar" was reaped, they turned to another part for their subsistence. This practice is still followed in some sparsely-populated mountain districts, but, with the growing population and culture, the people have taken to the so-called "wet" rice culture, which has been carried on since immemorial times on the same fields, and gives a far richer harvest.

Since historical times rice has been the principal food of the native, and, although he supplements it with other articles of food in times of want, he is so used to it that he only speaks of having eaten when his fare has consisted of "nassi" (cooked or, rather, steamed rice).

II. The Rainfall.

It is obvious that, in a land where the principal product of the soil needs such a quantity of water, the rainfall is of vital importance; and the study of the meteorologic phenomena has been a subject of care to the Government, which, since 1879, has published annually a record of the rainfall in the Indian Archipelago. In this book the daily observations are given for 109 places in Java and 117 places in other islands. In later years private industry and the irrigation service have multiplied these observations considerably, so that the results from some 450 stations more can be found in the "Natuurkundig Tijdschrift van N. I."

The data from these different sources have made possible the construction of the lines of equal yearly rainfall on the map, Plate I. In making a few remarks on the results of 24 years' observation the writer will consult only the data of the Government publications. The highest figure therein amounts to 4 512 mm. at Alas Petoeng, on the slope of the Smeroe,* in East Java, 3 400 ft. above sea level, while, in the western part, Buitenzorg gives nearly

*** In the names of mountains and places the usual Dutch spelling is followed; *oe* is pronounced as *oo* in *good*, or the German *u*.**

the same quantity at 880 ft. An upper limit of 180 in. is exceeded, according to unofficial observers, who give 240 in., and once even 280 in., but these must be exceptional cases, and it is possible that all sources of error were not avoided. The least quantities in the tables fall in the eastern part of Java, along the seacoast, where Probolinggo, with 1 131 mm., or 28 in., has a minimum.

In comparison with British India the condition of Java is very favorable. In some portions of Punjab and Sind the annual rainfall does not reach 10 in.; in the plains of the Ganges and Jumna from 30 to 60 in. is a large quantity, and higher figures are found only in Eastern Bengal, in the Brahmaputra Valley and in the Western Ghats. The latter may be compared with the average of Java.

In order to give an idea of the distribution, heaviness and frequency of the rain in Java, the data for the twenty-four stations in Table 2 have been selected from the Government publications. The heights are reduced to English inches, and, next to the mean figures of the whole period of 24 years, are also given the figures for each of the ten previous years, 1893 to 1902, in order to observe the annual variations.

Though the difference between wet and dry years is very noticeable, the least annual rainfall never falls below a figure which may be called calamitous, in the sense in which the deficiency of the rainfall in British India is considered. In general, in India, a deficiency of 25% is likely to cause some injury to the crop, and a deficiency of 40% is called a severe drought.* On the highest normal rainfall of from 30 to 60 in., this means a reduction to 18 or 36 in., which is less than the scantiest fall of Java. In British India every severe drought is followed by a famine, but Java is not subject to such extremes. Nevertheless, the long periods of consecutive drought during the east monsoon are sometimes the cause of a serious scarcity in some parts of the island. This is felt especially when the rains in November are deficient and the fields cannot be prepared in time for the crop, or when they cease too early, before the crop has ripened. In both cases, and also to help the crop over intermediate droughts, irrigation is of the utmost value.

* "Report of the India Irrigation Commission, 1901-1903," Part I, General, p. 4. Calcutta, 1903.

TABLE 2.—RAINFALL AT TWENTY-FOUR STATIONS IN JAVA.

Station.	Residency.	Geographical length.	Geographical breadth.	Height above sea level (feet).	Distance from the sea (miles).		Annual Rainfall, in Inches.											Number of Rainy Days in a Year.		
							Mean of 24 years.	1893.	1894.	1895.	1896.	1897.	1898.	1899.	1900.	1901.	1902.	Mean.	1896.	1902.
Western Part of Java.																				
1. Serang	Bantam	106°09′ E.	6°07′ S.	100	6		75	77	61	72	55	63	85	72	84	101	68	148	112	126
2. Mr. Cornelis	Batavia	106°51′ E.	6°13′ S.	46	7		76	84	83	109	81	57	107	97	78	89	64	133	133	119
3. Buitenzorg	"	106°48′ E.	6°36′ S.	883	36		169	189	155	172	131	165	168	176	172	193	156	218	198	184
4. Tiandjoer	Preanger Regencies	107°08′ E.	7°49′ S.	1 570	50		100	87	107	111	88	100	85	105	108	105	88	180	173	157
5. Bandong	"	107°36′ E.	6°55′ S.	2 380	42		70	60	79	66	69	83	63	73	88	65	41	140	137	122
6. Indramayoe	Cheribon	108°19′ E.	6°19′ S.	10	3		62	53	84	78	62	51	63	56	72	67	59	112	91	97
7. Bangadoea	"	108°19′ E.	6°28′ S.	50	10		77	75	85	72	77	55	67	67	73	79	36	114	92	71
8. Cheribon	"	108°34′ E.	6°43′ S.	......	Seacoast.		90	93	77	101	103	83	87	92	93	78	78	134	125	84
						Mean...	90	90	91	97	83	82	91	92	96	97	74	...	...	...
Central Java.																				
9. Tegal	Pekalongan	109°08′ E.	6°51′ S.	......	Seacoast.		72	68	70	62	70	71	93	84	78	107	92	99	91	84
10. Pekalongan	"	109°40′ E.	6°53′ S.	......	Seacoast.		86	87	85	103	90	80	95	99	63	91	99	143	125	114
11. Tjilatjap	Banjoemas	109°01′ E.	7°44′ S.	......	Seacoast.		146	159	113	134	98	113	114	118	240	147	69	189	145	126
12. Gombong	Kedoe	109°30′ E.	7°36′ S.	56	10		129	135	136	111	120	101	129	97	150	132	84	167	153	115
13. Karangkobar	"	109°45′ E.	7°17′ S.	3 410	26		165	148	158	164	148	146	?	148	182	167	154	232	182	197
14. Poerworedjo	"	110°02′ E.	7°41′ S.	150	11		102	90	102	93	105	92	109	106	147	81	77	151	147	110
15. Kendal	Semarang	110°11′ E.	6°05′ S.	......	2		74	124	83	96	70	63	59	76	69	92	83	116	105	95
16. Magelang	Kedoe	110°13′ E.	7°28′ S.	1 275	35		116	111	102	107	119	90	97	113	148	109	86	172	163	151
						Mean...	111	115	106	109	103	94	107	105	135	116	93	...	...	...
Eastern Part of Java.																				
17. Djokjakarta	Djokjakarta	110°22′ E.	7°48′ S.	380	35		86	96	84	97	107	68	86	77	111	78	75	130	130	90
18. Toeban	Rembang	112°04′ E.	6°54′ S.	......	Seacoast.		53	60	50	50	45	51	70	40	68	73	38	91	85	69
19. Bodjonegoro	"	111°54′ E.	7°07′ S.	50	22		73	88	?	78	79	74	81	53	79	86	60	112	89	102
20. Kediri	Kediri	112° 0′ E.	7°49′ S.	230	43		68	78	54	?	69	52	53	48	80	66	61	95	90	60
21. Grissee	Soerabaja	112°40′ E.	7°09′ S.	......	Seacoast.		62	61	60	74	58	52	61	56	62	68	36	106	108	84
22. Probolinggo	Pasoeroean	113°13′ E.	7°44′ S.	300	1		44	70	42	28	51	28	55	43	53	56	45	79	86	67
23. Pekalen	"	113°18′ E.	7°46′ S.	320	7		65	82	69	75	71	59	55	56	57	58	58	119	131	87
24. Banjoewangie	Besoeki	114°23′ E.	8°13′ S.	16	1		58	48	59	69	45	48	68	49	63	121	66	104	74	63
						Mean...	64	73	61	67	66	54	66	53	72	76	55	...	...	...

A second reason for irrigation is found in the richness of the water in fertile silt which restores to the soil the elements which the rice uses for its nourishment. As a rule, the rice fields are not manured in any way, and, because this crop takes only small portions of nitrogen, the restoring power of air and plentiful water seems to be generally sufficient.

That severe droughts may occur, may be seen from the last three columns in Table 2, where the average number of rainy days is compared with those of two very dry years, 1896 and 1902. Especially in the lowlands, the number fell short of the average by from 20 to 40 per cent.

III. Water Supply from Rivers and Other Sources.

Owing to the peculiar form of the island, there are innumerable little streams by which the profuse rain runs back to the sea, and these streams, when uniting, form rivers of no great capacity. Where stone, bamboo, old cocoanuts and other temporary materials were at hand it was easy for the people to throw temporary bunds or weirs across these little streams in order to force the water into primitive canals and to their fields. Where the rivers were shallow, native skill and patience, in former days, was sufficient to construct the necessary works in order that the "sawahs" or wet rice fields got the necessary supply for the tilling and growing. When the rains were heaviest, the streams occasionally destroyed the temporary bunds, but mutual help, or for larger works compulsory labor, in the form of "heerendienst" or "dessadienst," was always available to repair the damage. With these primitive means it was rarely possible to utilize the water of the greater rivers, and the works attempted in that way by native chiefs generally failed, for want of scientific plans and money to execute them.

It would be impossible to give a catalogue of the manifold water-courses and streams that furrow the Island of Java, but in Table 3 are given the areas of the catchment basins, and the greatest and least supplies of some of the main rivers.

The figures for the greatest and least discharge of Indian rivers are always very uncertain. If the catchment basin is small, a single exceptional shower causes a rise of the water which, in the

mountains, is almost instantaneous and is called by the natives a "banyir." The dark muddy stream, laden with the trunks of trees and the remnants of copse wood torn from its place, is signalled by a dull roaring, and, in the mountain valleys, it advances like a huge wall of water, tearing everything with it in its headlong course downward. Gradually, the great velocity of the water is tempered, and, in the lowlands, the rising of the rivers, though far more rapid than in the main rivers of the great continents, becomes more normal.

TABLE 3.—DATA RELATING TO SOME OF THE MAIN RIVERS OF JAVA.

Name of river.	Residency.	Area of catchment basin, in square miles.	Approximate discharge, in cubic feet per second.		
			Greatest.	Exceptional.	Least.
Tjioedjoeng	Bantam	665	35 000*	......	700*
Tjitaroem	Batavia and Preanger	1 500	40 000*	......	1 000*
Tjimanoek	Cheribon and Preanger	1 280	25 000	32 000	600*
Pamali	Pekalongan	340	24 000	34 000	250
Tjomal	"	290	20 000	53 000	600*
Toentang	Samarang	240	25 000	38 000	600*
Serang	"	326	18 000	70 000	600*
Solo	Soerakarta, Rembang and Soerabaya	5 950	70 000	90 000	530
Brantas	Kediri and Soerabaya	3 725	40 000	60 000	2 600
Pekalen	Pasoeroean	65	11 300	20 000	170
Sampeyan	Besoeki	462	17 000	70 000	400

* The figures are approximations.

Because the movement of the water in the upper course of the river is not a permanent one, it is very possible to observe there a much greater discharge per second than in the neighborhood of the sea, although the supply is increased by tributaries. The greatest discharge is practically of interest when permanent head-works are to be made, in order to give them sufficient capacity. The least discharge occurs at the end of the east monsoon, when, often during a period of 5 or 6 months, no rain at all has fallen and the south-east tradewind has contributed to take the moisture from the atmosphere. In some of the rivers the discharge may dwindle away to practically nothing, and where the water is used for watering the so-called second crops, *viz.*, maize, cotton, beans, monkey nuts, inland

potatoes, tobacco and the like, the area cultivated must be greatly reduced and the crops which require the least moisture must be selected; or the culture must be stopped altogether.

As far as irrigation is concerned, the most interesting is the low-water discharge of the rivers, when the rains in the lowlands are not yet sufficient. On the plains near the sea the frequency of tolerably high water in the great rivers during the west monsoon may also be of importance, because dependence is frequently placed on canals which can only take water if the level exceeds a certain limit. The condition of these plains is similar to that of the greater part of the Nile Delta, and to that of the plains of Sind, watered by the Indus, in former days. The flood canals on which the Nile Delta depended are now being gradually changed to perennial canals.

Owing to the great difficulty of making proper weirs across the main rivers, their discharge is seldom used directly for extensive irrigation works, and only in later times have attempts been made to complete the existing systems of minor works on tributaries, with the utilization of the main rivers by the aid of weirs.

That in the smaller rivers "banyirs" are frequent, but generally subside in a few hours, is due to the heavy showers which sometimes fall in a single mass. The above mentioned rain observations give daily quantities, which in some cases amount to 12 in., and days of 4 in. rainfall are frequent at every station. Though the records are given daily, the water of a heavy shower falls generally in from 4 to 6 hours, and there are records of rainfalls of 3 in. in 1 hour and 0.1 in. in a minute.

Silt.—As the water of the Javanese streams generally does not pass through lakes, where it might be cleared, and as the banks are subject to erosion, so that portions of the soil, with trees and all, are frequently carried downward, the quantity of silt carried is enormous.

As to the largest river, the Solo, we learn from ample researches that every cubic foot of water annually running down to the sea contains 1 000 gr. of silt. When the water is high every cubic meter contains 6 kg., which corresponds to 2 600 gr. per cu. ft. (The Mississippi at New Orleans, according to Mr. L. H. Gardner, carries from 450 to 1 200 gr. per cu. ft.)

The Serang River, near the head-works of the Demak irrigation,

causes much trouble at the intake of the canal water, and contains there from 1 500 to 1 600 gr. of silt per cu. ft. The nature of the silt differs. In the Solo River it is chiefly clay, but in the Brantas it contains 21% of sand. The coarser material is of no value, and the sluices are generally shut when the river is swollen by "banyir," but the more tenuous silt, which can float a long way in the canals, is rich in nutritive constituents. According to researches on the canal water in the delta of the Brantas, it contained quantities of from 0.35 to 0.65% of phosphoric acid, 0.43 to 0.60% of kali and 0.25 to 0.27% of nitrogen.

Length and Cross-Section of Rivers.—The length of the greatest river of Java, the Solo, which takes its course eastward, is not greater than 350 miles. Next follows the Brantas, which makes a sharp circuit around the Kawi and Kloet volcanoes, from the sources to the sea, with 120 miles (100 miles to the great movable dam at Lengkong, where the river divides into two arms).

The breadths of the rivers vary, but seldom exceed 200 to 400 ft. In the lower course of the Solo the depth at high water at Karanggeneng (25 miles from the mouth) is 33 ft. and at low water 13 ft., the water level being generally higher. This river is navigable for sea-going native boats to Babat (some 40 miles), and upward to Soerakarta, the capital of a native state, for smaller craft and rafts in the rainy season. Since the general introduction of railways, the carriage of goods by boats has nearly ceased on this as well as on other rivers. The Brantas, however, which contains more water in the dry season, is used for the carriage of sugar and other goods in competition with the railways. Generally, the water traffic is of only a local character, and is of no importance in the great export trade.

A remarkable feature of the rivers, which pass from the mountain-valleys to the lowlands, is, that formerly they frequently inundated the adjacent plains and the silt fell down near the banks. The country between two rivers remained low and gradually sloped up to the river banks. All the rainfall could not pass away and swamps were formed, which were not fit for agriculture, but often an ample vegetation therein withstood the dry monsoon. From this point of view, these swamps or "rawahs" form a valuable means of subsistence for cattle, when fodder in a dry year is scarce. If the

depth is not too great, parts of such swamps can be cultivated as rice fields ("sawah rawah").

As the population grew more dense, the frequent overflows could no longer be tolerated, and dikes were made; but where they defended local interests, no general plan existed and their location and form were often defective. Banks were scoured out and were protected by spurs, which sometimes damaged the opposite side. In this way regular wars arose between the heads of adjacent districts divided by rivers, especially if, as in the case of the Tjimanoek and other rivers in Western Java, one of the parties comprised the owners of the "particular lands," which were sold in the beginning of the 19th century. Where the danger from inundation was very great, as in Demak, or where the normalization of the river was of vital interest, as in the case of the Brantas, the making of new dikes on a general plan, not by compulsory labor, but to be paid for in money, was taken in hand by the Public Works Department.

Other Sources of Water Supply.—When a comparison is made with British India, the above-mentioned report of 1903 gives (page 11) a grand total of 44 million acres under irrigation, partly from state works and partly from private works; and from these only the smaller half gets water from canals, while for nearly 13 million acres the supply is derived from wells and the remainder gets it from tanks and other sources. In Netherlands' India irrigation from wells is practically of no importance, for it is insufficient for wet rice culture. It is practised in Krawang as a means of supply when the peril of destruction of the crop by drought is imminent, but in these cases it is generally of small value. Only in the neighborhood of towns, where gardening or the culture of vegetables is practised, it occurs, but, generally, the "dessa" wells are in use for the household. Tank irrigation is somewhat more common, but is considered far inferior to canal irrigation. Frequently, on the particular rice lands in Batavia the crop is nearly wholly dependent on water storage in marshes or "rawahs." These are maintained carefully and at the same time afford a favorable opportunity for the shooting of wild ducks. In the lower Solo Valley some tanks are very useful for the crop when this is retarded by the overflow of the river having prevented working the rice fields at the proper time. In the southern hills of that valley some storage works of

great dimensions are under consideration; and when there is occasion to construct them in other places, without sacrificing too much ground already under culture, the system may perhaps be extended, especially in the hills. Up to the present, irrigation has been generally considered sufficient only when the water is derived from canals.

IV. Cultivated Area and Crop.

In accordance with the figures collected in that valuable periodical, the "Koloniaal Verslag," an annual report on the political and economical condition of Netherlands' India, a statement relative to the seventeen provinces or residencies, into which Java is now divided, is given in Table 4. Formerly, there were twenty-two provinces, but, for the sake of economy and simplicity, Krawang has been joined to Batavia, Tegal to Pekalongan, Japara to Samarang, Bagelen to Kedoe, and Probolinggo to Pasoeroean, since January 1st, 1901. In the first columns the area and population are given, and in the following columns other information, after deducting the so-called "particular lands,"* because the figures for the cultivated area, rice crop, irrigation, etc., which are given in other parts of the "Koloniaal Verslag," refer only to the Government districts. Two residencies, Soerakarta and Djokdjakarta, are protected principalities or native states, and the agricultural data for these cannot be obtained. For the sake of comparison, attention is called to the density of the population in other countries, for instance, in Great Britain, the density is 345 per square mile, in Belgium 595, in Holland 400, in France 185, etc., while for the United States it is only 21.75.

Deducting the area of the "particular lands" and principalities, the area of the Government districts is 42 477 sq. miles, or 27 166 000 acres. Of the lands annually sown ("particular lands" omitted) the area is 7 252 300 acres. The ratio of cultivated land to the total area, therefore, is 26.7 per cent.

Comparing with Punjab, Bombay, Bengal and Madras,† in round numbers, 40, 50, 40 and 60% are found. Relatively, there remains in Java more ground to be tilled than in those countries.

* Day, p. 367.

† Report of the (British) Indian Irrigation Commission, 1901-1903, Part I, General, p. 10.

From the 7.25 million acres actually sown, nearly one-half is cultivated a second time every year. The first crop is generally rice, *viz.*, 5 100 000 acres, and 2 150 000 acres of other crops. As a second crop, only 415 000 acres of rice are mentioned, as against 3 100 000 acres of other products. Of the latter, no definite figures relating to irrigation are known. Generally, no second crop is possible without canal water, but the quantity of water required is far less than for rice, while some of these cultures can subsist with one-tenth of the full supply.

The statistics given for 1902 accord very well with the want of rain in that year, as mentioned previously. The failure of the rice crop amounted to more than one-tenth for the whole island, and was particularly severe in Krawang (Batavia), Demak and Grobogan (Samarang), and on the Island of Madoera, where no powerful rivers are available. In these districts and in the lower Solo Valley, in Soerabaya and Rembang, the failure was partly due to want of water, but, generally, it was due to the previous waterlogging by inundation and the ensuing delay in the culture, when the rains began to fail before the crop was ripe.

When the percentage of rice fields actually irrigated is considered, it must be borne in mind that in the "Koloniaal Verslag," from which these figures are taken, the area of irrigated fields is given, without mentioning the canals from which the water is taken and without stating that the most primitive and insufficient contrivances may have been considered as giving flowing water to the fields. The others are designated as solely dependent on rain, "tegal" grounds, not fit for rice culture, and "sawah-rawah." From the peculiarity already mentioned, that irrigation from neighboring streams or brooks is accomplished very easily, it is clear that high figures from this list do not especially indicate extensive irrigation works in that province. In the following the writer will examine the particular conditions in each province.

V.—Actual Condition of the Different Provinces, from the Point of View of Irrigation.

Bantam.—This province, the most westerly part of the island, has suffered from severe blows. In 1883 the eruption of Krakatoa

TABLE 4.—AREA, POPULATION, CULTIVATED AREAS, ETC., IN JAVA.

Province.	Area, in square miles.	Population.	Population per square mile.	Area annually sown, in acres.	Area sown a second time, in acres.	Total area cultivated yearly, in acres.	1902. Rice fields first and second crops harvested, in acres.	1902. Percentage of rice fields irrigated.	Fields where the rice crop failed in 1902, in acres.	Failed rice crop 1902, in percentage of sown fields.
Bantam.										
Government dist.	2 875	747 262	260	213 000	21 600	234 600	193 000	37.75	10 900	5.3
"Particular lands"	115	64 908	565	26 400	......	....	....	....	......	....
Batavia.										
Government dist.	1 230	377 788	308	108 300	4 100	112 400	67 000	63	38 500	40
"Particular lands"	3 260	1 560 218	475	470 000	....	....	....	....	....	....
Preanger Regencies	7 800	2 435 582	312	1 065 000	180 000	1 245 000	812 000	53	13 200	1.6
Cheribon.										
Government dist.	1 913	1 515 213	792	415 000	105 000	520 000	336 000	85	11 700	3.4
"Particular lands"	707	145 466	206	96 500	....	....	....	....	....	....
Pekalongan.										
Government dist.	2 120	1 877 329	880	475 000	223 000	698 000	337 000	77	44 000	11.2
"Particular lands"	10	15 847	1 584	1 270	....	....	....	....	....	....
Samarang.										
Government dist.	3 089	2 634 914	850	772 000	465 000	1 237 000	490 000	61	187 000	27.5
"Particular lands"	61	50 101	820	20 500	....	....	....	....	....	....
Rembang	2 660	1 470 525	550	484 000	336 000	820 000	368 000	13	35 000	8.7
Soerabaya.										
Government dist.	2 202	2 306 490	1 040	620 000	278 000	898 000	405 000	48	99 000	19
"Particular lands"	18	54 419	323	4 400	....	....	....	....	....	....
Pasoeroean.										
Government dist.	3 378	1 821 289	548	470 000	370 000	840 000	246 000	81	2 600	1
"Particular lands"	2	3 178	1 589	790	....	....	....	....	....	....
Besoeki	3 900	837 081	214	324 000	246 000	570 000	176 000	88	700	0.4
Banjoemas	2 140	1 368 298	635	342 000	170 000	512 000	281 000	57	5 800	2
Kedoe	2 110	2 358 545	1 120	555 000	440 000	995 000	500 000	75	23 500	4.5
Djokdjakarta (Native State.)	1 200	1 084 327	903	....	....	....	....	....	....	....
Soerakarta (Native State.)	2 400	1 512 773	625	.. ....	....	....	....	....	....	....
Madioen	2 250	1 233 653	548	386 000	212 000	598 000	307 000	80	27 200	8.2
Kediri	2 700	1 512 921	556	383 000	200 000	583 000	245 000	67	33 500	12
Madoera	2 080	1 758 511	840	640 000	342 000	982 000	167 000	8.5	62 500	27.3
Total for Java	50 220	28 746 638	572	7 872 160 (Principalities excepted.)	3 592 700	10 845 000	4 930 000	59.5	595 500	10.7
					Government districts only.					

swept away all the inhabitants and the vegetation of the low country adjoining the Strait of Sunda. Afterward, heavy fevers, and a riot caused by fanaticism, contributed to impair the situation, but, notwithstanding all these misfortunes, the country is now tolerably well-to-do. The greater portion of the south is thinly peopled; in the jungles near Java's First Point the tiger is still searching for his prey, and the infrequent communities of natives live on the crops of dry rice fields or the products of the forest. Here, near the springs of the Tjioedjoeng River, is found that curious people, the Badoewis, last remnants of the old kingdom of Padjadjaren, whose fall, after centuries have passed, is still bewailed in this remote portion of the primitive forests.

The cultivated grounds comprise one-eighth of the whole area, and are found in the north around a mountain range with the Karang and the Poelasari in the middle and ending in St. Nicholas Point. On the eastern slope the most fertile fields are found in the district of Pandeglang, easily getting its water from the adjoining streams. Lower down, the lands near the sea get water from different canals fed by the Bantam River, but in the Tjioedjoeng Delta the area requiring water is greater than can be afforded by the existing system. These lands are dependent on rain, and in order to make the crop less risky and to give the means to till the ground sooner—in order to sow rice, which remains longer in the field, but yields a much greater crop—it has long been under consideration to make an entirely new irrigation work, taking water above a permanent weir to be constructed in the Tjioedjoeng near Rangkasbetoeng. The main canal must follow the very low valley of that river, and, therefore, would be in a somewhat precarious position in case of extraordinary floods; and, on account of its length and the necessary minor works, about $1 500 000 would be required to improve the irrigation of 57 000 acres. Up to the present time, it is thought that this project is not yet ripe for execution.

On the northern slope of Mt. Karang, wholly enclosed by hills, there is in this province a lake, called Dano, with a steep outlet to the Strait of Sunda. In the rainy season the water of this lake stands high, and in the dry season a large cultivable shore is left, but plans to utilize this lake or swamp, for the storage of water which could be drawn by a tunnel to the northerly fields, have not yet been put into execution.

Batavia.—When we follow the great plains in the north of Bantam toward the east and cross the Tjioedjoeng and Tjidoerian Rivers, which form the limit of the two provinces, we pass by extensive "particular lands," which stretch to the west, south and east of Batavia and give valuable rice crops, mainly because they may be watered easily from the little coast rivers, which run to the Java Sea. In the eastern portion of the country, around Batavia, there are marshes or low grounds, where the water is stored carefully by the landowners; and, as far as the great Tjitaroem River, the abundant rice crop gives a lively trade, as Chinese merchants buy the rice for export. Passing the Tjitaroem, the adjoining districts of the former province of Krawang are the least prosperous of those surrounding Batavia. Here, toward the sea, the country is still in its primitive state. The rivers form extensive marshes, where, when the inundation is not too heavy, the rice plant grows with enormous fertility, but the crop is subject to failure by overflowing. The parts which silt up above the level of inundation are entirely dependent on rain, for the river is too deep to spread the water on the fields by primitive native works. In order to water some 200 000 acres and secure their crop, it has been planned to make a weir across the Tjitaroem and construct a huge main canal through the steep and winding banks of that river. The danger of landslips in the canal, the great height to which the river must be dammed, the interests of the upper and lower grounds adjoining the river, and other difficulties, have as yet deterred the Government from the execution, which requires a capital outlay of at least $7 000 000.

Turning to the "particular lands," south of Batavia, there are two interesting canals, the oldest which have been dug in the interests of European estates.

The visitor to Buitenzorg, the seat of the Governor General, and renowned for its Botanical Garden, " 's Lands Plantentuin," sees at the east side the Tjiliwong River, which meanders through that garden, and at the west the Tjidani River, with Mt. Salak in the background.

"The Oosterslokkan" or East Canal was dug by the proprietors of the lands in the eighteenth century. It took its water from the Tjiliwong some 5 miles above Buitenzorg, and in 1753 it was com-

pleted as far as Batavia. From the double design, watering the rice fields and carrying the products to the market, the latter proved unfeasible on account of the great slope of the country, which would have made locks and other works necessary. A year after the completion, the intervention of the Government was found to be necessary in order to make proper regulations for the distribution of the water between the landowners. Every one of these got the right to make an inlet of certain dimensions and to build a weir of timber and bamboo across the stream to force the water into the sluices. It was regulated in this manner in 1777, but in 1843 the landowners were ordered to make good permanent works in masonry or timber. Afterward the volume of water was increased by utilizing another river.

The East and West Canals take their origin in the neighborhood of Buitenzorg and water the "particular lands" of Batavia. They have a very great slope, and, in order to prevent the scouring of the bed by too fast a current, this slope has been in later years gradually broken by falls of masonry, constructed by the landowners or the Government. Fig. 1 gives two examples of the former, constructed some sixty years ago. This illustration is taken from a paper* by Mr. Homan van der Heide, who points out that while sloping falls are likely to scour the canal at the down-stream side, and vertical falls are frequently damaged if the cistern is not very deep, these works give a curious example of a third contrivance, which has proved practical, with a minimum quantity of masonry. The slope and the retaining walls are of light brickwork and the difference in height between the upper and lower levels is from 20 to 25 ft. Commonly, the supply is 350 or 400 cu. ft. per sec. (the greatest supply being two or three times that quantity). The water attains such a velocity along the slope that the thickness of the jet is reduced to 2 ft. or less. By a slight incline upward at the toe, the jet is projected some 20 or 30 ft. from the lower retaining wall and reduced to a broad spray. In this way the impact is not so strong and the canal bed is hollowed out only to a moderate depth at some distance, but is not scoured just below the toe of the work. The greatest depth measured was 12 ft. below the normal bed level, at a distance of 60 ft. from the transverse retaining wall.

* *Tijdschrift van het Koninklijk Instituut van Ingenieurs,*" 1897–1898.

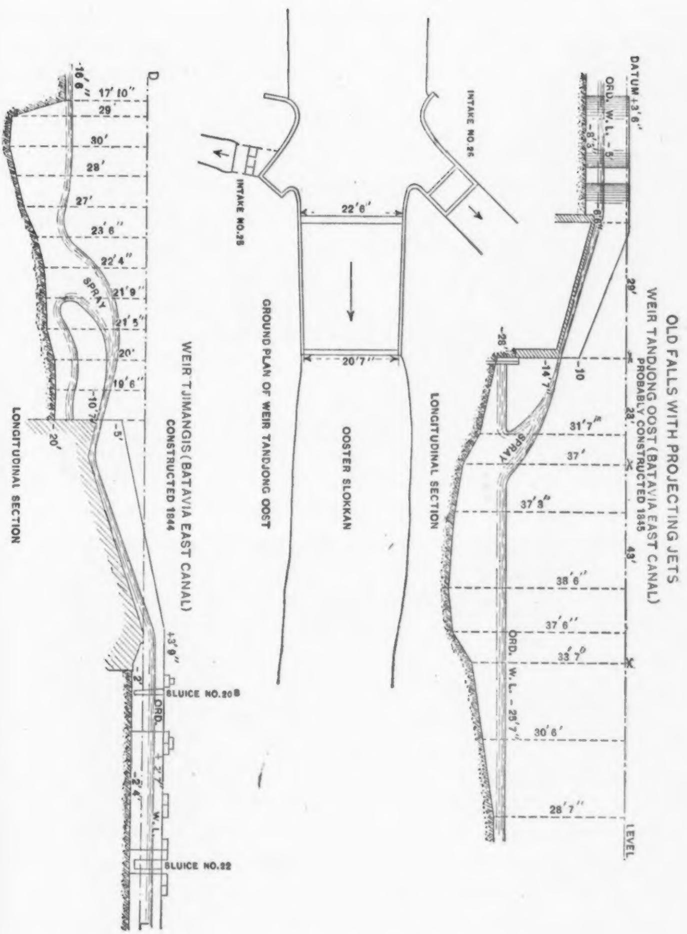

OLD FALLS WITH PROJECTING JETS
WEIR TANDJONG OOST (BATAVIA EAST CANAL)
PROBABLY CONSTRUCTED 1845
DATUM +3'6"
ORD. W.L. -5'
LEVEL
SPRAY
ORD. W.L. - 25'7"
LONGITUDINAL SECTION
INTAKE NO.26
INTAKE NO.25
22'6"
20'7"
OOSTER SLOKKAN
GROUND PLAN OF WEIR TANDJONG OOST
WEIR TJIMANGIS (BATAVIA EAST CANAL)
CONSTRUCTED 1844
SPRAY
SLUICE NO.20B
SLUICE NO.22
ORD. W.L.
LONGITUDINAL SECTION

Fig. 1.

During its long existence, the "Oosterslokkan" has been scoured out in such a manner that the bed, nearly everywhere, is some 30 ft. beneath the ground level, and the breadth has increased accordingly. At the weirs or falls of permanent construction, which exist now at the different inlets, this condition does not endanger the effective working of the canal. The supply may increase in the wet season to 1 750 cu. ft. per sec., but in the dry season (August to October) it does not fall below 280 to 350 cu. ft. Though the catchment basin above the weir is only 61 sq. miles, the great flow is due to the great rainfall in the mountains south of Buitenzorg.*

The "Westerslokkan" or West Canal was made, according to a resolution of 1776, when the Tjidani was dammed at Empang near Buitenzorg, under the supervision of the Dutch engineer, who took care of the East Canal. This was in order to increase the supply of the first-named canal and to use that for renewing the water of the canals in the Town of Batavia. Afterward the works fell into disuse, but in 1817 permits were granted to landowners in the neighborhood to make watercourses from that river, and gradually the inlets and permits increased, so that this canal is no more a feeder from the Tjiliwong, but is cut through to the lowlands and divides there into branches which irrigate the western part of the Batavia lands. The capacity at the head-works at Empang varies from 1 000 to 200 cu. ft. per sec.†

The idea of expensive remodelling of the canals and their defective works has been given up, because the cost would be too great a burden for the landowners, and as they are the proprietors who get the rent of the land which, in the Government districts, goes to the treasury, there is no reason to pay this outlay out of the latter.

At present the Government pays the staff for the supervision of the water distribution, while some repairs and new works are under the charge of the owners of the "particular lands." The Government's yearly outlay for ordinary repairs and supervision is estimated at $16 000 for the entire system.

* There are some other minor canals which take water from the Tjiliwong River, and among these may be mentioned the Tjiballok, a canal which has an open inlet 9 miles up stream from Buitenzorg. After watering the Bloeboer Estate, formerly a property annexed to the charge of the Governor General, and afterward taken over by the Government, it flows through the gardens of the Governor's residence and unites with the canal next to be described. It has also a great slope divided by falls.

† A detailed record of the inlets of both canals, with dates of permits and names of weirs, is found in the "Report on the Indian Public Works" for 1894, p. 239 *et seq.*

FIG. 1.—WEIR, WITH VERTICAL FALL, TJIBOLOE, IN THE WEST CANAL, BATAVIA.

FIG. 2.—TUNNEL HEAD AND CROSS-DRAINAGE, TJI DJAMBÉ.

Preanger Regencies.—Comparing the general area (2 990 sq. miles, or 1 913 600 acres) with the area actually sown, the ratio is not as unfavorable as in Bantam, giving 22.75%, but still the southern part of this great province is very sparsely inhabited. In the northern part, the districts of Soekaboemi and Tjiandjoer, with their copious rainfall and many streams, are easily irrigated, and this was also the case with the surroundings of the capital, Bandoeng. Certain tracts, however, were not so favored. Of these, attention is drawn to the Tjihea plain, east of Tjiandjoer. About 14 000 acres of this plain could not be watered, because the Tjisokkan and the Tjihea, between which rivers, tributaries of the Tjitaroem, it was enclosed, were too deep to be drawn off by the ordinary native means. In passing from Tjiandjoer to Bandoeng, on the railway, the barren aspect of this portion was in striking contrast with the adjoining districts. On account of this, the Government was induced to execute a remarkable irrigation work in that part of the province. The great difficulty of drawing water from the deep Tjisokkan was surmounted by making a head-work up the river in the forest and constructing the main canal partly in the steep banks of that river and partly through tunnels. On the first three miles there are four tunnels of 295, 146, 490 and 136 yd., some deep cuttings, three masonry aqueducts for cross-drainage and other minor works. The tunnels are in rubble masonry 8.5 ft. wide and 7 ft. high to the top of the arch, which is segmental, with 1⅔ ft. rise. In the plain, the main canal, which has a capacity of 265 cu. ft. per sec., divides into a network of distributaries which are provided with falls, aqueducts, siphons, bridges and sluices; so that for the entire area the water distribution is now completely arranged. The cost of the first two sections of the main canal amounted to $155 000 or $56 000 per mile, while the succeeding miles of that canal, as long as its capacity was not greatly reduced by distributaries, cost only 25% of that amount. This work, with the expensive head canal, which reminds one of the Verdon Canal in France, although on a reduced scale, and the elaborate manner in which the distribution of the water is provided, so that the whole cost about $25 an acre, is an example of the utmost limit of state enterprise in irrigation. A private company could not have undertaken the work with the most modest expectation of gain, and it will

be an interesting contribution to the results of irrigation politics if, in the long run, this work remunerates the capital outlay, in the form of land revenue and other indirect advantages combined. Where by the steadily growing population, it opens a new field of action for native settlers, it seems no fit beginning that on a large portion of the newly watered grounds a lease of emphyteutic tenure ("erfpacht")* was granted to a European.

The Preanger Regencies, which have a valuable water supply in their rivers, and in which, as the culture extends, interesting irrigation works may still be constructed, are also delivering part of that supply to the lowlands, according to rights established in olden time, when the hill country was still nearly uninhabited. Important examples are afforded in the Regency of Soemadang where the northeast frontier adjoins the "particular lands" of Kandanghauer and Indramayoe West, in the Residency of Cheribon. These extensive estates of 503 and 204 sq. miles, respectively, of which 21% is cultivated, would be worthless if the water from the Tjipannas and the Tjiplang, tributary to the Tjimanoek, were not dammed in the highlands and the water conducted in canals to the seacoast. The right to do this seems to date from the beginning of the 19th century or earlier, when the lands were sold. Though private property, the thousands of natives living on these lands have as much claim to that water as their younger brethren in the hills; and now some 3 000 acres in the formerly uninhabited districts could be tilled if the water were not wanted for the lands further down stream. This is an example of the complications which must arise in irrigation matters as the population becomes more dense.

Cheribon.—Next to the two great "particular lands" west of the Tjimanoek, and eastward of that river, there is in this province an extensive plain which is wholly dependent on irrigation, because the rains are scarce and the heavy clay ground, in the dry season as hard as stone, requires a copious watering before it can be tilled. With native means the head river could not be attacked, but an eastern tributary, the Tjikeroe, running down from Mt. Tjermai, was dammed and the water gradually conducted downward by a canal, stretching laterally to the Tjimanoek. The "banyirs" of the

* Day, p. 378.

TJIHEA IRRIGATION WORKS

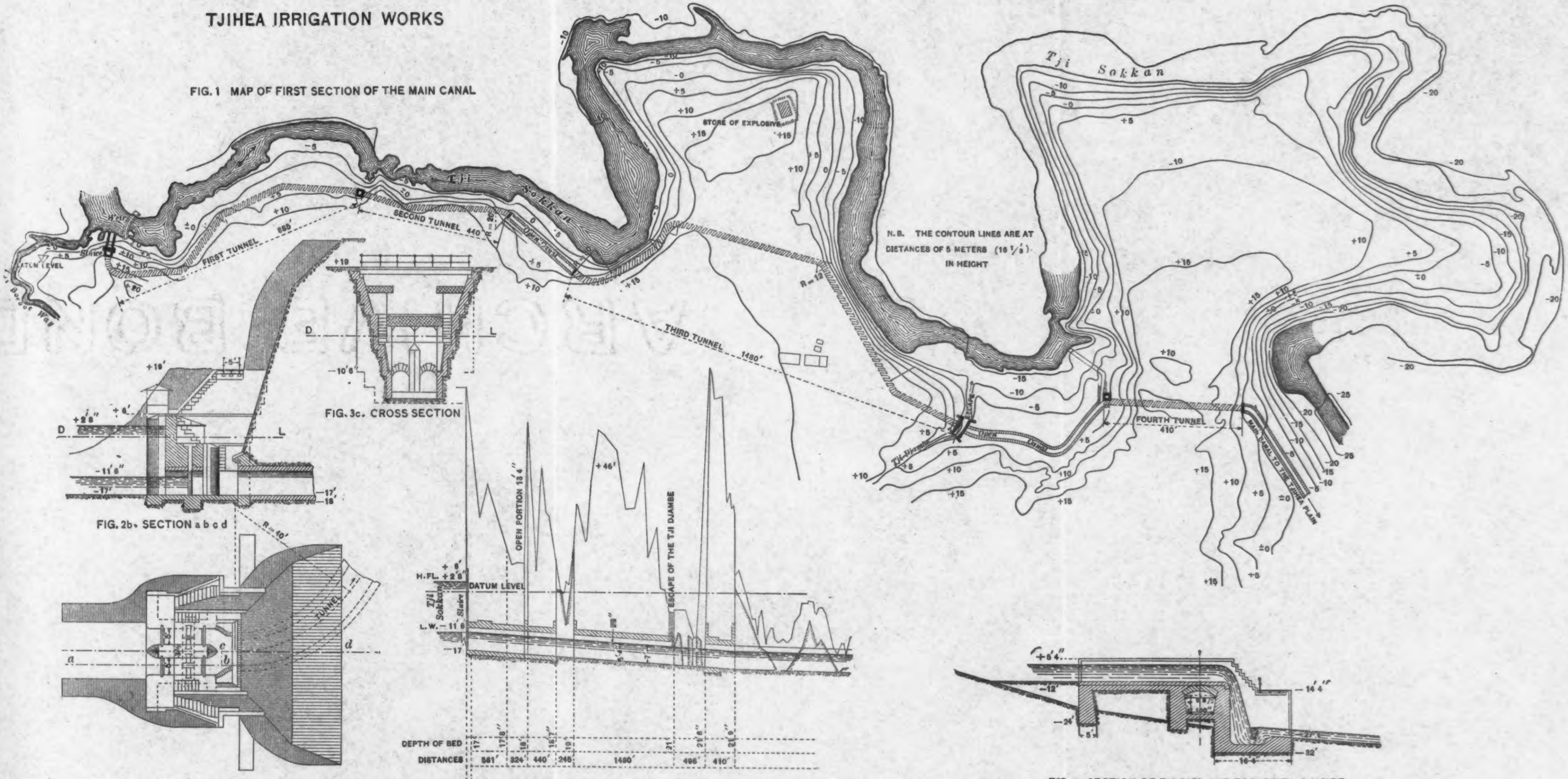


FIG. 3a. PLAN OF SLUICE

FIG. 2 LONGITUDINAL SECTION OF TUNNEL PORTION

FIG. 4. SECTION OF TUNNEL AND ESCAPE TJI DJAMBE

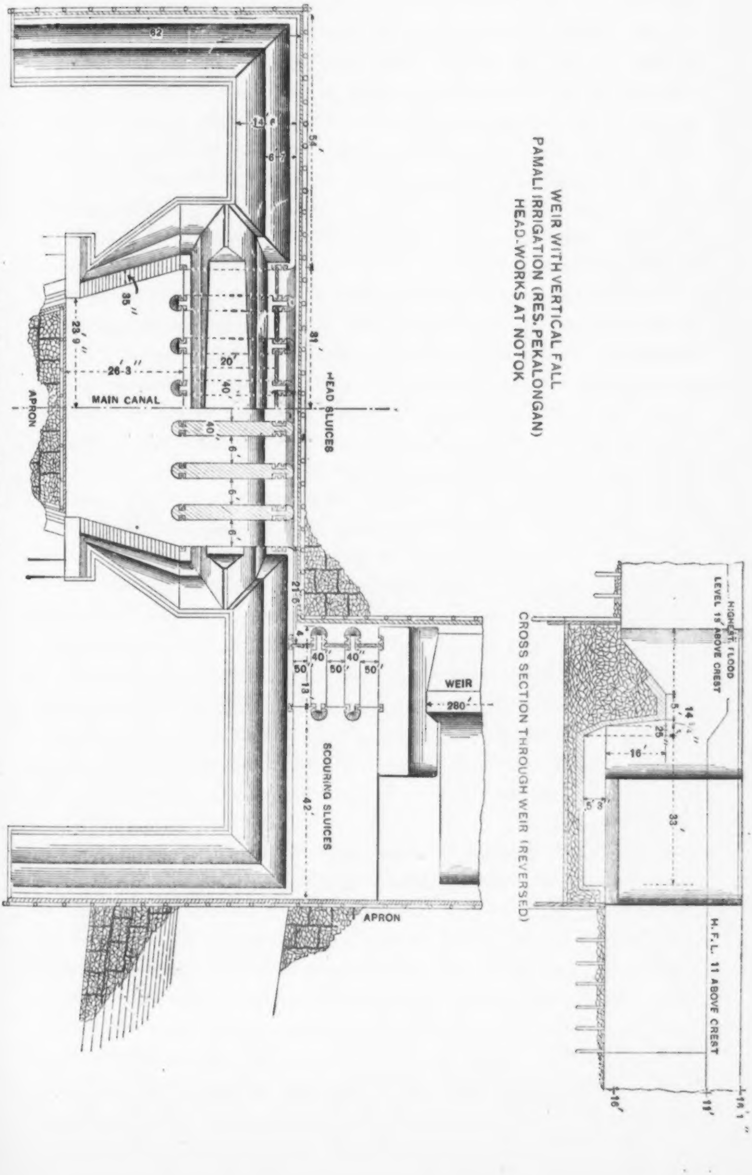
river, generally subsiding in one day, ran into the canal, which had to be provided with escapes to the Tjimanoek. The canal and the river are both in the plain, and the slope is small, so that in the upper portion overflows on the wrong side happened occasionally, and the high water of the Tjimanoek did much damage, not only to the canal but to the villages, roads and fields. In order to remedy this evil, and to afford the necessary security against the failure of the supply of irrigation water by the rupture of native constructions, the Government has made sluices, which take the water immediately from the Tjimanoek, and thus the whole system is bettered and extended.

Turning to the country south of Indramayoe, along the great trunk road of Daendels which passes from the Preanger frontier by the capital of Cheribon, and further along the seacoast to Samarang, in the residency now composed of Tegal and Pekalongan, other circumstances give special interest to the irrigation question, *viz.*, the many sugar manufactories in this part of the northern coast plain of Java. By a tramway, which, in fact, is a simply constructed railway, running 16 miles an hour, Karang Sambong, at the old ferry across the Tjimanoek near the sugar mill of Kadipaten, is connected with Samarang and from there a line continues through the country eastward. Between the two last-named places, and within a distance of 200 miles, not less than thirty-five sugar manufactories are working and have a vital interest in the proper watering of their cane fields. In Cheribon twelve factories occupy yearly a plantation of 20 000 acres, producing 1 000 000 picols of sugar (64 444 tons of 20 cwt.) of a gross value of more than $2 500 000. The fields for this crop are hired from the natives, because they are not allowed to sell their property to Europeans or other non-inhabitants; a measure intended to protect them against the loss of their means of subsistence by the allurement of money advances. Sugar cane exhausts the fields greatly, and only once in three years can it be cultivated on the same land. In this part of the island, therefore, 60 000 acres of the best land are used for this culture. The cane is on the field about 16 months, and though it requires only one-third as much water as rice, it must have this water at times when the available supply is scarce, and the conflict between the interests of native planters of second crops and the owners of

the valuable sugar crop, as well as the rivalry between adjoining undertakings, gives some trouble, and requires a closer supervision than in the patriarchal Indian society of old. While this question will be considered in another paragraph, it is proper to remark at this place that the irrigation of the fields north and east of the slope of the Tjermai is relatively an easy matter by making primitive weirs in the rivers running down from that mountain. For the frontier of Tegal (Pekalongan), however, a more elaborate head-work was necessary in the Losari River or Tjisangaroeng for watering the district of Losari. This head-work was completed in 1882 after a design now more generally adopted: A masonry dam with a sloping apron, a scouring sluice in it at the side where the water is taken, and a regulating sluice or intake at right angles with the weir at the mouth of the canal. This weir is submerged at high water, and, as its height is only 3 or 4 ft. and the depth of water on the crest may be three or four times as much, the obstruction to the flow of the river is unimportant. The openings of the regulation inlet are small, and the supply is controlled by sliding gates worked by screws. The main canal has a capacity of 300 cu. ft. per sec.

Pekalongan.—Passing to the former residency of Tegal, a center of activity in irrigation works, combined with not less necessary drainage works, is reached. Omitting the latter, attention is drawn to the Pamali works in the division of Brebes, which were completed only recently. The head-work on the Pamali River is made at Notok (along the river some 25 miles from the sea). The main canal follows the right bank and, at 5 miles below the weir, is divided into a branch for the irrigation of the grounds on the east side and another for the west, which is carried over the river at Pontjol in a splendid iron aqueduct. The masonry weir at Notok (Fig. 2) 280 ft. long, with three scouring sluices of 4 ft. has a fall of 16 ft. at low water. It is not constructed with a sloping apron, but with a vertical fall and a cistern below it, in order to break the impetus of the flow on a water cushion. Fig. 2 is an example of the common arrangement of the head-works constructed in later years. The head-sluice of the canal consists of a series of narrow openings, closed with timber sliding shutters, while a scouring sluice in the weir can be opened to clear the silt before the sluices of the

WEIR WITH VERTICAL FALL
PAMALI IRRIGATION (RES. PEKALONGAN)
HEAD-WORKS AT NOTOK



CROSS SECTION THROUGH WEIR (REVERSED)

PART OF GROUND PLAN (CANAL SIDE)

FIG. 2.

main canal. As the breadth of the latter is less than that of the sluices between the wing walls, these gradually converge to the bottom width of the canal. The scouring sluices are separated from the weir by a wall, which is indicated in the cross-section (and which, therefore, is reversed from left to right). This system is well adapted to rivers which do not carry heavy rubble which may damage the floor of the cistern below the water cushion. In the main canal there is a scouring sluice to avoid the silting up, a drawback of Javanese canals to which attention will be called when describing the Demak works.

The Pamali works are completed by a whole network of distributaries and drainage canals, and form a design for which much credit is due to the engineers who constructed it. To the east of the Town of Tegal, the Waloe works deserve attention, as far as they were necessary to set right what was spoiled by native practice. The river was dammed so thoroughly that the whole supply passed into the canals, which, though badly scoured out and becoming less fit for irrigation, were not capacious enough to convey properly the flow during high water, thus causing great damage to the fields by overflowing. This work, restoring to the river the task of carrying the surplus water to the sea and to the canals the irrigation water, was begun with the head-work. Afterward, a regular distributing system was added. More to the east, a territory hitherto totally waste for want of water, was irrigated from the Tjiomal, in connection with other minor works, which need not be described. A description of the difficult drainage question in the lowlands, between the Tjiomal and Seragi Rivers, is also omitted, in order to give a glance at the head-works which claim attention in the adjoining province.

Samarang.—Samarang, after being joined with Japara, now the greatest province of Mid-Java, contains, east of the capital, the extensive plain of Demak, which is prolonged south of the isolated Mt. Moeria, by the Valley of the Joana River and forms a territory for the greater part lying at so low a level that in former days frequent disasters from inundation took place. The Toentang to the left, the Serang to the east, the latter partially flowing over into the basin of the Joana, were wont to submerge the country in such a way that, in the beginning of the past century, Daendels could

speak of the inland sea, east of Samarang, which stretched as far as the middle of Japara. When he wanted to construct the great post road running the length of Java, this tract was one which gave the most trouble, and in order to serve the drainage as well as the communication by land and water, a canal was dug from Demak to the frontier of Japara, uniting the two rivers. This canal could take the drainage water of the south, and the excavated ground was useful for the building of the roadway. In the parts which did not lie as low as the marshes near the seacoast and part of the Joana basin (probably an old sea strait), the cultivation of rice has been practised since immemorial times, for there exists a report on the probable causes of the retrogression of the rice culture, dating from nearly the same time as Daendels' road making, proving that the crop in these regions was then as precarious as it was in later days, while occasional mishaps are generally ascribed to the bad measures of the Government. Now, for this region, the latter is not wholly without fault, for, in 1849, in the time of the culture system, the heavy compulsory labor, and unsuccessful essays with forced tobacco planting, in conjunction with bad weather and vexational dealings of the inland chiefs occasioned a famine which was unparalleled in Netherlands' India and reminds one of the famines which are rife in British India. This misfortune, causing the death of thousands of natives, determined the Government to construct different works for the relief of the country. In half a year 50 000 000 cu. ft. of ground were dug for drainage canals to the sea, and, in order to water the fields, a weir in the Toentang River was begun, by which two great irrigation canals could be supplied.

Fifty years ago engineers in India were not very experienced in this kind of work, and the weir, being a slope of rubble stones put in quadrangular spaces of masonry walls, proved to be not sufficiently strong against the attacks of occasional "banyirs." Frequently, the stones were thrown out, the toe of the work was washed away and heavy repairs were necessary to avoid a complete rupture and the loss of the water level necessary to feed the canal. After frequent reconstructions, and by lengthening the rubble apron to a great extent, the work was made safe and now does well. In the course of time, however, the cultivated area extended. The supply

of the Toentang was not sufficient for the whole area, and in 1873 there was again a scarcity which made one fear a repetition of the famine of 1849. The making of new works was planned and more drainage canals were begun, while, for the sake of giving more certainty for the crop, a weir in the Serang was designed, a work formerly deemed impracticable. This river is subject to great variations of flow. In the dry season the supply of some of its tributaries, as the Loesi, draining the plain of Grobogan, dwindles to nothing, and if the rains are heavy a flood of 70 000 cu. ft. may occur. This splendid head-work was ready in 1889, and also the greater part of the main canals and minor works, the cost aggregating \$2 000 000. Since that time, however, different accessory works have been joined to it, so that the total capital outlay may be put at \$3 500 000. The weir, which has the ogee form, lengthened by a rubble apron, has no scouring sluices to get rid of the silt, and the crest lies some 18 ft. above the lower toe of the apron. In order to avoid the silting up of the sluice gates of the canal, the inlet was put at a distance of 600 ft. from the weir, and the two works were joined by expensive revetment walls. It was expected that the silt would gently slope up against the crest of the weir and that the sluices would be situated outside that slope, but this forecast has not been realized, and the mass of silt which enters with the canal water is enormous. In order to avoid the gradual decrease of the water supply by the narrowing of the cross-section of the canal, a sluice is built across the canal, ¼ mile from the entrance, with an adjoining escape to the river. From time to time the sluice is shut and the escape opened, and in the canal the deposited silt is put in motion by a pair of boats furnished with a set of rakes and dropping boards.*

The silt clearing in this manner costs 0.1 guilder per cu. m. (\$0.11 per cu. ft.).

The aggregate supply of the main canals derived from the two rivers is scarcely sufficient to give a thorough watering to all the rice fields now under cultivation. This has led to a system of alternate irrigation, regarding which something will be said in a following paragraph.

Another peculiarity of the Demak works, in connection with the

* *Le Génie Civil*, March 23d, 1888.

interests of the lowlands at the other side of the Serang River, is the general system of river dikes introduced in this region, and which formerly overflowed yearly. Protected by these dikes, cultivation is practised on fields formerly submerged, while the rivers, with their heavy silt-laden water supply, are forced into narrow channels. The water level rises higher, the bed silts up and, when the dikes are no longer able to withstand the pressure, their breaking is disastrous to the valuable crops or the skilful network of irrigation canals.

In order to preserve the latter, the left dikes of the Serang are always made stronger than the right ones, and, if a rupture takes place, the water must run down the valley of the Joana River, causing protests from the owners of the sugar cane now cultivated in the lowlands which were marshes before.

Banjoemas.—Turning to the south coast of the island, the sparsely inhabited southern Preanger is followed by jungles in the adjoining province of Banjoemas, and only in the valley of the Serayoe are found the ordinary rice fields, drawing water as far as possible. This valley is separated by a hill range from an extensive coast plain which is continued in the south of the residency, Kedoe, formerly called Bagelen. Different works to ameliorate the irrigation have been executed in later times, and, for an aggregate area of 226 000 acres, according to the last available report, $750 000 were spent. Among the most noteworthy works are those which form the Singomerto compound.

Kedoe.—The southern part of this province, formerly called Bagelen, is classical ground for irrigation, because the extremely dense population made it necessary to make the most of the great number of little rivers found there.

A valuable contribution to the knowledge of this country was given some 30 years ago by an estimable officer of the civil service, since deceased,* and it would be desirable if more exact data of this kind were collected, in order to note the advance of the country. In 1874 this province had 437 canals for distributing river water on the fields, and 1 470 canals drawing water from sources. The aggregate length of these canals was more than 900 miles. In the dry season they watered 22 000 acres, and in the wet season 140 000

* Natuur- en Staathuishoudkundige Atlas der residentie Bagelen, door Jhr. J. F. W. van der Willige von Schmidt auf Altenstadt, Controleur. Leiden, 1874.

acres. The area actually irrigated cannot be compared with this, because in the last colonial report the figures refer to the new province as combined with Kedoe. This province of Bagelen is densely peopled: In 1870 there were 1 061 876 souls and in 1900 this was increased to 1 542 141, or an increase of 48% in 30 years. The population per square mile increased from 777 to 1 181.

The figures relative to cattle are not as favorable, as they do not indicate a similar increase. In 1874 there were 8 784 horses, 93 008 buffaloes and 102 768 bullocks, and in 1900 these figures were 10 705, 59 470 and 103 620, respectively, so that the cattle used for plowing had decreased, and particularly the buffaloes. The cultivation of the swamps, which afford less fodder in the dry season, may be one of the causes of this decrease, and has engaged the serious attention of the Government.

The northern part of the new residency, Kedoe proper, surrounded by mountains, with the twin volcanoes, Soembing and Sindoro, in the west, and the other twins, Merapi and Merbaboe, in the east, is one of the most splendid regions of the whole island, and was of old called "the garden of Java." From north to south it is traversed by the Ello and Progo Rivers, which unite not far from the Djokdjakarta frontier, and these rivers give an ample supply for irrigation canals, partly by native contrivances, and partly by weirs and other works constructed by the Government.

Djokdjakarta and Soerakarta.—These provinces, also, have their own native irrigation works, but these are not under the direct control of the Government. An extensive and somewhat hazardous scheme, to make a weir in the Progo and dig a main canal in a difficult tract, has not been executed, because the Sultan of Djokdjakarta could not guarantee an adequate revenue from the native fields, and the European land holders were not inclined to pay enough for the water. Where the capital outlay for this work was great, and the benefit to the agriculturists not so obvious, there was no reason for the Government to take this upon itself in a native principality, while its own provinces were still in need of so much.

Rembang.—Returning to the north coast, the extensive province of Rembang is one of those which is suffering in some parts from want of water and in others from too great a profusion of it. It

is traversed by the Solo River, which afterward flows to the sea through the adjoining part of Soerabaya, formerly in a direct line into the strait of that name, opposite the Island of Madoera, but since 1887 its mouth has been diverted to the north, in order to carry its silt to the Java Sea, according to a theory of silt deposit of that river which now begins to be recognized as erroneous.

Ten and more years back, that theory being generally adopted, a cutting of the Solo from Pelangwot through the hills at the north of the valley right to the sea coast at Sidayoelawas was deemed a still better remedy and absolutely necessary. In that case the 40 miles of the actual lower course would be deprived of fresh water and a scheme of a large irrigation canal for the whole valley, of some 100 miles in length and carrying a supply of nearly 8 000 cu. ft. per sec. was planned and actually brought into execution. The Solo River was to be dammed by a formidable weir, at a place called Ngloewak. The crest of this weir would be some 40 ft. above the toe, but this head-work has not yet been seriously begun. Afterward, the execution of the scheme proved far more expensive than was foreseen by the design, as the weir and the provisions for cross-drainage for some 60 brooks and rivers on the first 60 miles of the main canal would offer almost insurmountable difficulties. Again, the greater part of the fields to be benefited were not wastes, but already under cultivation, even with a scanty water supply from sources, tanks and minor works, but all these would have to be sacrificed to the great canal scheme. The failure of one of the great aqueducts or of one of the displaced watercourses would cause the nearly irremediable subsiding of the flow of the main canal, and this danger was greater than that of starving the crop by drought under the actual circumstances. An expensive silt clearing in the main canal could be foretold. All these different technical drawbacks were sufficient reason to renounce the plan, but the worst was that no adequate increase of the crop could be expected in order to repay in any direct or indirect way the enormous outlay. Financially speaking, the scheme proved a failure and was stopped, much to the regret of its former fervid advocates, but there is no doubt that it was a wise decision.

Although the scanty water supply of the rice fields in Rembang in most places is not to be remedied, in the lower part of the Solo

Valley, lying in the province of Soerabaya, storage works of rain water, and particularly a better drainage of the low lying grounds, could still be executed to the benefit of that culture. On the other hand, the richness of Rembang lies in its forests and sources of kerosene oil. It is now connected by tramways with the harbors of Samarang and Soerabaya, and there are good expectations for the future, as regards its timber and industrial resources.

Soerabaya.—Although the lowlands of the northern and western parts of Soerabaya are subject to heavy inundation from the Solo, and from the rain running down the adjacent hills—and the precarious situation of the fields, which sometimes give a luxuriant crop and sometimes fail, cannot be remedied altogether—the southern districts have to cope with the "banyirs" of the Brantas basin; but the grounds, especially the delta of Sidoardjo between the two branches into which the river divides at Lengkong, are in a much better condition. This is evident from the great many sugar manufactories found in this part of the residency, *viz.*, 37, with nearly 58 000 acres under cultivation.*

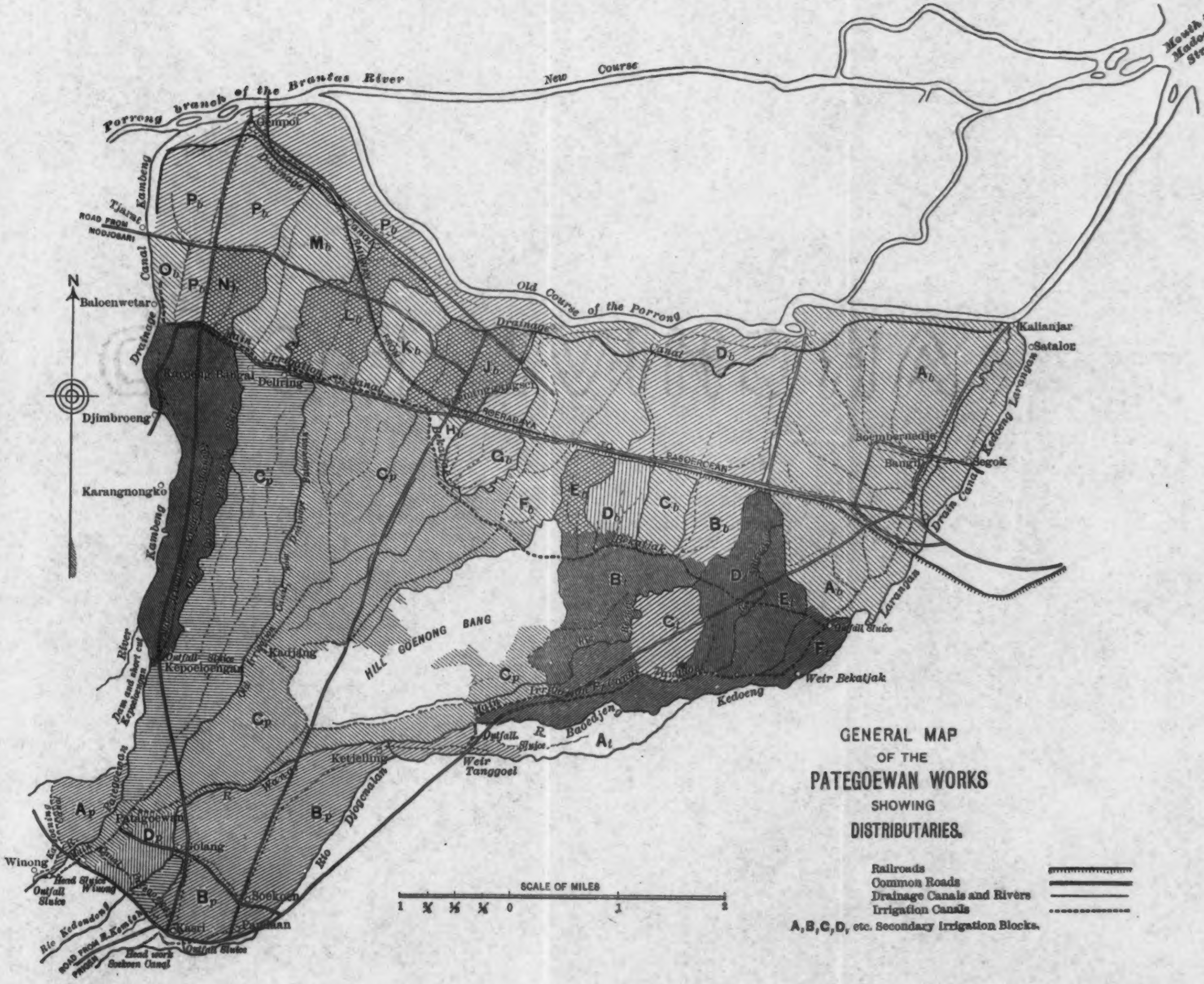
The delta of Sidoardjo, where alone a dozen sugar factories are working, derives its prosperity from one of the oldest of the great irrigation works constructed by the Government nearly half a century ago in order to remedy the dangerous condition into which the Brantas and its affluents were brought by native weirs and watercourses dug without any system or regard to the interests of others. The high-water supply of the rivers enclosed between dikes did not allow of a permanent weir, and therefore a movable dam of very peculiar device was planned and executed in 1857. The work is built on such bad ground that the whole construction had to be founded on piles.

In general, the work consists of two abutments and nine intermediate piers. The left abutment is prolonged at right angles to the work and has two sluices at some distance from each other, each with three openings shut by wooden sliding gates.

The clear distance between the abutments is 402 ft., divided by nine piers of 8.2 ft. thickness into ten openings of 32.8 ft. clear space, in which ship-gates of a special sort are sunk and rest in

* In the whole island of Java there are 188 sugar manufactories, which occupy 232 000 acres of cane fields. Of these, 38 mills also buy sugar cane from the natives. The general product is 14 500 000 picols, or some 900 000 tons of sugar.

PLATE IV. VOL. LIV. PART C.
TRANS. AM. SOC. CIV. ENGRS.
INTER. ENG. CONG., 1904.
DE MEYIER ON
IRRIGATION IN JAVA.



GENERAL MAP
OF THE
PATEGOEWAN WORKS
SHOWING
DISTRIBUTARIES.

Railroads
Common Roads
Drainage Canals and Rivers
Irrigation Canals
A, B, C, D, etc. Secondary Irrigation Blocks.

iron grooves. The piers, in the direction of the river, have a length of 41 ft., and the floating ship-gates, which can be lowered by partially filling them with water, are sunk against the grooves near the up-stream end. Formerly, the design was to put them between the piers against grooves, anchored in the down-stream pier heads; but that system was abandoned because it was difficult in practice, the down-stream grooves being now reserved for the sinking of sleepers when the openings have to be shut while a ship-gate is in repair, or when it is wanted to give back-water to the gates. The water is dammed to 12.5 ft. above the floor. In the dry season all leakage is prevented by carefully stanching the fissures with dry leaves and other stuff, in order that no water may be lost; but in the rainy season the gates are lifted and afterward floated to a harbor out of the way. This takes place when the discharge of the river is great. In fact, at the highest floods the piers are submerged to a depth of 4.5 ft. and the abutments are only about 1.5 ft. above the water level. In that case the ship-gates would float out of the grooves, and it is necessary to remove them in time.

The water of the Brantas carries a sharp silt, consisting partly of sand, and, in the long run this makes grooves in the strongest material. The floor between the piers and the apron, over a distance of 28 ft., consisted of timber, bolted to the woodwork of the pile foundation, but between the piers below the gates the attack of the water was so severe that frequent repairs were necessary, and, from 1863 to 1876, from 6 to 19 years after the completion of the works, the wooden floor was protected by fastening heavy cast-iron plates upon it, with long screw-bolts, sunk in the sleepers. The heads of the bolts were afterward chiselled off, to get a smooth surface.

The ship-gates are of wrought-iron plates on a framework, and when empty, float with a draft of 2.5 ft. When the weir is to be shut, the ship-gates, five of which are lying on each side near the up-stream banks of the river, are guided to place by hawsers slung around bollards fixed on the tops of the piers and abutments. When one side of the door is abutting the pier head, it glides to the groove on one side of the opening and the force of the current makes it pivot around this point, thus bringing it in contact with the other side. By letting in the water the doors are lowered on

the sills. The ship-gates have worked well, and, though the handling needs more people than would be feasible where labor is dear, and precautions must be taken in beginning the lifting of the doors by pumping, by driving wooden wedges between the door and the grooves, in order to avoid a sudden shock at rising, when the buoyancy begins to exceed the friction, they have the sanction of nearly half a century of good practice, and the whole work is much to the credit of the late Mr. H. de Bruyn, the engineer, afterwards Director of Public Works, who constructed it.

The two regulation sluices, lying near one another on the left side of the river, give access to two different main canals, one of which already existed as an uncontrolled river. The subdivision of the water in a regular network of distributaries was not planned at the time, and much was left to local circumstances. From this point of view, improvements are still to be made. The Mangettan canal had formerly a supply of from 600 to 800 cu. ft. per sec. for more than 36 000 acres, and the Porrong canal a little less for 21 000 acres. When the supply of the river was tolerably sufficient, this discrepancy was not severely felt, but in later years the distribution of water must be made more in proportion to the needs, for in the upper course of the Brantas more use is made of the water, especially in the province of Kediri.

Kediri.—The province of Kediri must be considered with reference to the districts of Waroedjayeng and Kertosono, on the left bank of the Brantas. Formerly, these districts were generally waste, but now the rice fields require water over an extent of 43 000 acres. In 1901 the building of a regulating head for the main canal, taking water from the Brantas, was granted at Mritjan, at an outlay of $52 000. The digging of this canal and its distributaries has been begun. The regulator cannot take water if the river is below a certain level, in order not to interfere with the interests of agriculture and sugar planting down stream, but here is a new instance of how, in the long run, the interests of the culture in the upper and lower regions are gradually interfering, in connection with the growing population.

Madioen.—This province, between Kediri and the principality of Soerakarta, is enclosed by mountains, and the hilly Patjitan division stretches to the south coast. In the river plains there is

PLATE V. VOL. LIV. PART C.
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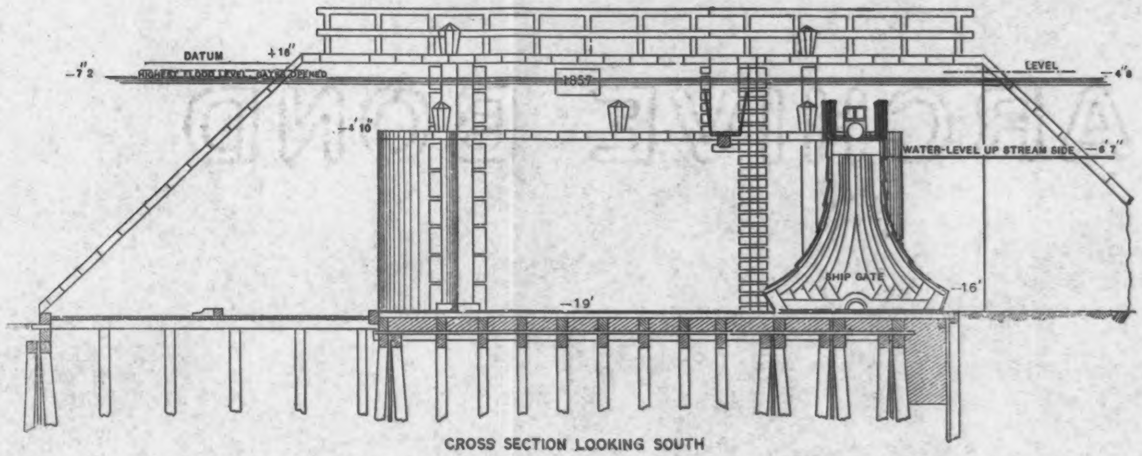
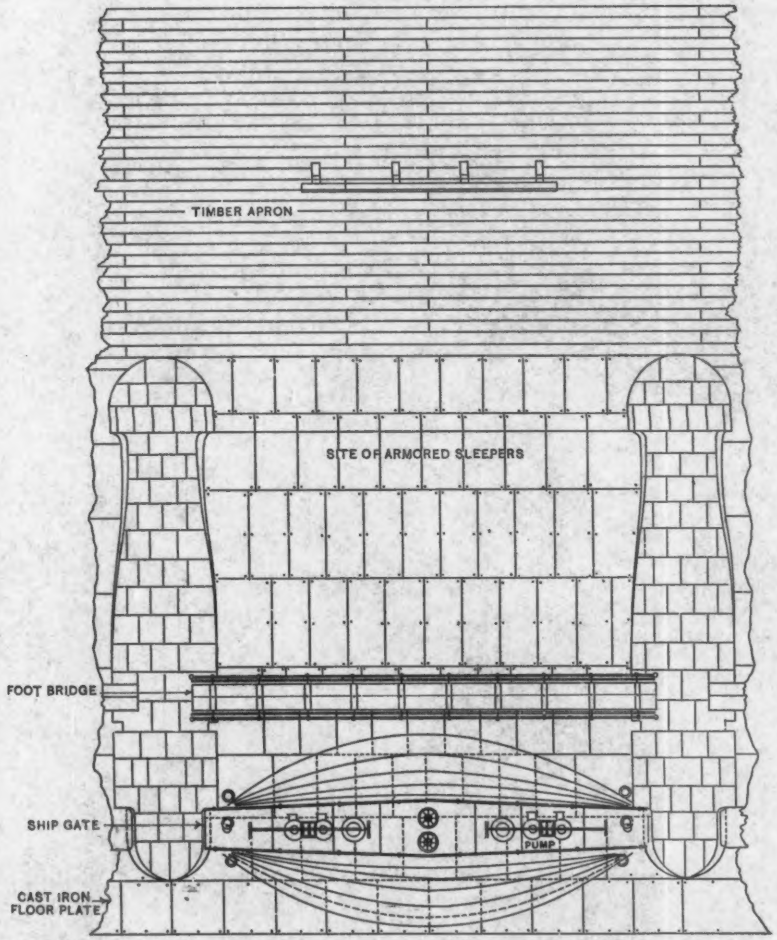
DE MEYIER ON
IRRIGATION IN JAVA.

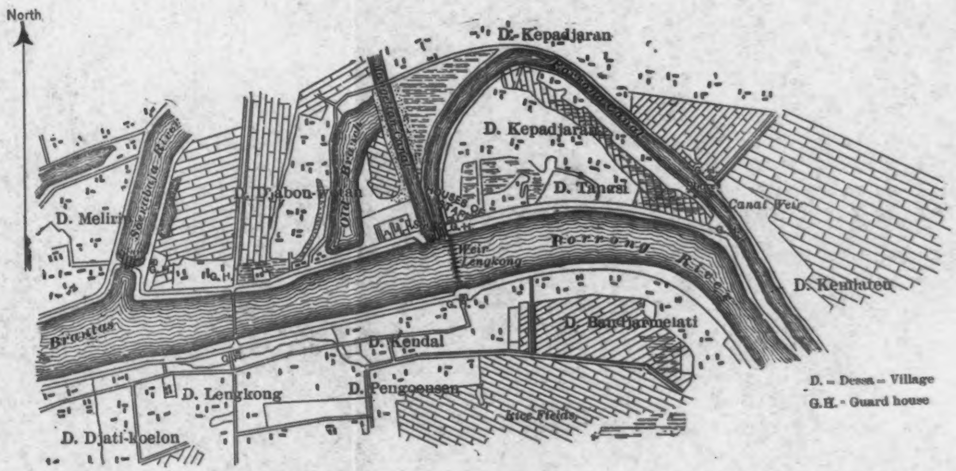
MOVABLE WEIR AT LENGKONG (SOERABAYA).



CROSS SECTION LOOKING SOUTH



GROUND PLAN OF AN OPENING WITH SHIP GATE



SITUATION OF THE WEIR OF LENGKONG AND THE SLUICE ON THE SOERABAYA BRANCH AT MELIRIP

generally sufficient water available from the affluents of the Madioen River, which, at Ngawi, unites with the Solo, now breaking through the hills in the valley of that river already described, but in prehistoric times, when the eruptive products of the Willis volcano had not yet advanced as far to the north, it is very probable that these combined waters* found their way directly to the Brantas Valley and thence to Madoera Strait, the northern valley being a sea gulf. Works of great engineering skill are not to be found in Madioen, but in the divisions of Magetan and Ngawi much money is spent in improving the distribution of the water, which must serve for an aggregate area of 84 000 acres. Here, as well as in Kediri, are also different sugar factories.

Pasoeroean.—Pasoeroean is now combined with Probolinggo, and adjoins the southeast of Soerabaya and for some 13 miles the Porrong River. The latter is the southern branch of the Brantas below the movable weir of Lengkong, and is the frontier between both provinces. Just to the south of that river there is an irrigated tract, called the Pategoewan works, which has an area of 11 200 acres, and may be considered as a model of the more modern arrangement of a well-considered distributing system, with all the works necessary for the proper maintenance of the canals and the division of the water according to the area for which it is intended. It is said that, from this point of view, the arrangements are to be considered as a limit, and that afterward, as to dimension of regulators and watercourses, no works of as much detail will be constructed.

In the other parts of this province, which are at the west side of the mountain range of which the Bromo and Smeroe are notable features, the works consist generally of canals of minor importance, where the aid of the Government is necessary only from time to time to overcome extraordinary technical difficulties, as, for instance, in the Molek Canal, a large aqueduct to pass a deep valley, by which the area under irrigation could be extended, and the construction of regular head-works and other accessories was justified.

Passing to the eastern part of Pasoeroean, on the frontier with Besoeki, another great irrigation work is to be noted, the Pekalen

* It was in this region that Professor Dubois found the bones of the prehistoric man, *Pithecantropus Erectus*.

works, a territory in the Gending and Padjarakan districts* having a gross area of 17 000 acres, of which 18% will eventually be planted with sugar cane. The main canal runs parallel to the sea coast at a distance of some 6 or 7 miles, and the tract between those limits is divided into thirteen sections, each provided with a main distributary and the necessary drainage canals, so that the details of the distribution and drainage can be regulated. As the Pekalen River is a powerful stream in the wet season, and the branches and watercourses were injured by native dams, the head-work and the proper separation of irrigation and drainage canals gave much trouble, and the capital outlay for the whole scheme amounted to $435 000. The principal works and main canals are estimated to have cost $18 per irrigated acre, and the minor works of distribution $7.75 per acre.

In order to make a proper comparison with other works, it is noted that $170 000 of the outlay were necessary for ameliorating the already existing irrigation, and that where the land tax was increased, this increase had to be considered as the revenue of the balance of $265 000, used for extending the irrigated area and improving the distribution. This was at the time calculated at 5.5%, not including the indirect revenues or advantages due to the work. It is worth noting this figure, as in most cases it is difficult to ascertain the direct advantage of irrigation works in Java, because no separate water rate is raised, and the land tax is not always increased in the tract benefited, because, formerly, it was too heavy.

Besoeki.—This great province which, including Banjoewangi, forms the eastern part of Java, is a country where the high mountain territory of the Jang plateau and the Raoeng were visited so seldom, that half a century ago some parts were still marked on the maps as unexplored. Only the seacoast near Sitoebondo and along the Strait of Bali were cultivated, but the road between Sitoebondo and Banjoewangi led through mere uninhabited jungles. At Sitoebondo, however, an irrigation work of ancient date is to be found, *viz.*, a permanent weir in the Sampeyan River. As far back as 1820 it is noted that this river was dammed 1.5 miles below Sitoebondo, and in 1832, nearer to it, was made a more per-

* A complete description, by the engineer who executed this work, Mr. A. G. Lamminga, is found in the *Tijdschrift van het Kon. Instituut van Ingenieurs*, 1894-1895, p. 93 *et seq.*

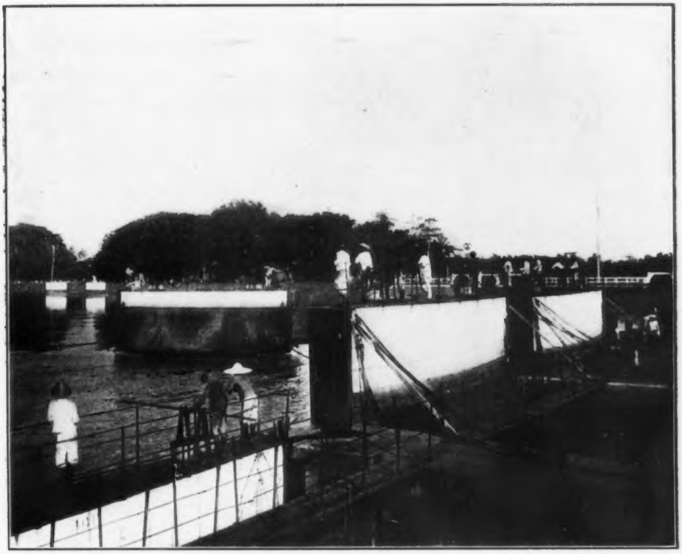


FIG. 1.—MOVABLE WEIR AT LENG KONG. SHIP-GATE BEING BROUGHT INTO POSITION.

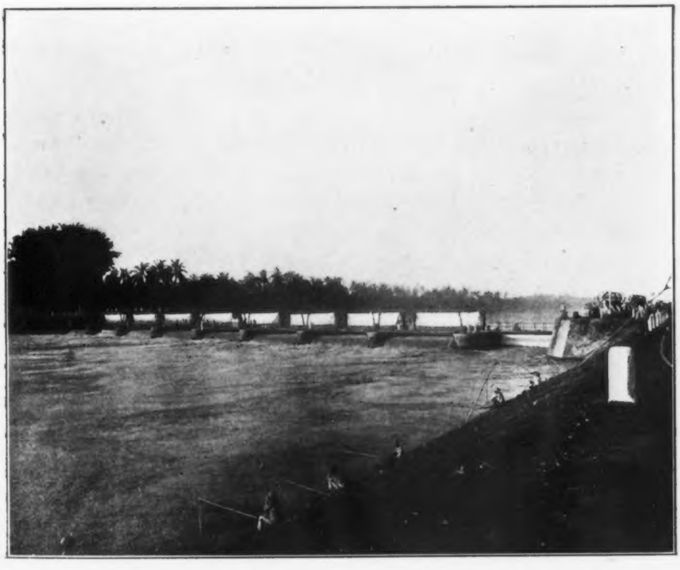


FIG. 2.—MOVABLE WEIR AT LENG KONG. SHIP-GATES FLOATING.

manent weir, consisting of a sort of framework of timber sleepers filled with stones. This work, being a dam 150 ft. long, 75 ft. broad at the lower part, and with a crest of 30 ft., had a height of 26 ft. It served for about 18 years, but then the woodwork was so decayed that another construction was thought advisable, because the necessary teakwood timber could be collected only with great difficulty in these regions. The further history of the work is very instructive, as to the force of the water and the small reliance that can be placed on seemingly rocky ground, here called "wadas." The weir with sloping apron, which was constructed, proved to be a failure, and the system had to be totally revised, before preventing wholly the danger of scouring away entirely the frequently damaged weir. This was done by making a long escape canal, which brought the high supply of the river in a great compass around the work. In later times the regulators and minor works, the canals and distributaries, were reconstructed, improved and enlarged. An irrigated area of 26 000 acres has required in after years a capital outlay of $386 000, the works being not yet wholly completed.

The growing population and the increasing culture of formerly waste land will induce the Government to construct more works in this province, in order to make the water of the different rivers available for the fields. In this line, surveys are begun in the southern division of Djember and in after years the country to the eastward will perhaps also claim the aid of the Government. In the province of Besoeki there is a striking example of the benefit of railways in a country otherwise not easy to be reached. It was in the beginning of 1903 that the last link of the great trunk line over Java from Anjer to Banjoewangie was made by the completion of the Kalisat-Banjoewangie line, a 54-mile section which runs for 26 miles through the primitive forest to the south of the Raoen Mountains. After the opening of this line it was remarkable to see how quickly the forest began to be cleared and cultivation by emigrants from other parts of the island was introduced. Without constraint, a new way has been opened here for the subsistence of that surplus of population, which is increasing at such a rate, under the peaceful and regular rule of the Dutch Government, that nervous observers are disposed to predict that Java is being ruined

by over-population. Where tracts like these and other extensive portions of the south of the island are still available, the dark prognostics of these melancholy prophets may be left unheeded for a long time.

VI. The Supervision of Irrigation.

Formerly, the supervision of the distribution of the water between the fields was almost entirely an affair of village policy, and where the interests of whole tracts or districts conflicted, the higher native officers or chiefs arranged the matter. In the days of the culture system, when water was wanted for the sugar cane and other Government crops, the influence of the European and native officers in this matter greatly increased, and later, with the growing area under cultivation, the increasing want of water made their intervention still more necessary. When extensive irrigation works were made under Government control, at first by compulsory and afterward by paid labor, that influence did not diminish, and the native regents, in their care for the well-being of their subjects have always shown a great interest in this branch.

In every district, a native supervisor, called "mantri-oeloe-oeloe," was the surveyor and mouth piece for the orders issued by the native officers. That the distribution between the cultivators did not always take place with the utmost impartiality, may be expected by those who understand something of the petty intrigues which are rife in a native society and are aware of the pressure which the more powerful can inflict on the weaker members of the community; but it could not be deemed the task of the Government to interfere in such details. Affairs began to change seriously, however, when the industry of Europeans spread over the most fertile parts of the island, and when the interests of the scanty second crop of the little peasant came in conflict with that of the cane fields of the great cultivators, or when these came in conflict with each other in reference to the rights to the water.

It is known* that in Java the rights in cultivated grounds cannot be transferred permanently to non-natives, and that the sugar mills must hire the necessary fields on short terms. They are understood to hire at the same time the rights of the field to the use of the water. For the sake of more regular planting, the aid

* Day, p. 372.

of the village heads is secured to get the necessary fields in great compounds, and, when drought is to be feared, the standing of the temporary owner of the cane fields is much stronger than that of the simple native cultivator in his neighborhood. The arrangement is made that the former shall take the water by daylight, the latter at night. That in such cases the former portion is the better is to be understood, and, when the values of the crops are compared, this is not wholly unjust. It is not impossible, however, that the native cultivators are less fairly treated. On the other hand, the stealing of water and the consequent strife between adjacent districts was not avoided, so that a more regular management of the irrigation in the most densely cultivated and peopled tracts began to be a matter which, more and more, attracted the attention of engineers and officers of the civil service, just as in a railway the care for proper operation comes to the front when the construction of the line is nearly completed.

The public works, including railways, telegraphs, postal communication, etc., of the whole archipelago are brought under a single department, that of Public Works. The section which more especially has the care of public buildings, highway roads, harbors, canals and irrigation works. consists of an establishment of 66 civil engineers of different ranks, who have all passed their examinations at the Polytechnic School in Delft, and a subordinate staff of 195 persons, called "opzichters," who pass a simpler examination divided into two grades. Those who have passed the examinations of the second and more difficult grade, in which practical knowledge is an important factor, are eligible to a higher grade, in which 23 places are available, with the ornamental title of "architect."

The bulk of common works, buildings, bridges, etc., in each province is supervised as Local Works under the direct orders of the "Resident" or Government commissioner. He is the head of the provincial "waterstaat," and has some officers of the "waterstaat" corps at his command to guide the work. This work is divided into "ordinary maintenance," "heavy repairs" and (entirely) "new works" of local interest. On the Island of Java, only six of the provinces have engineers employed in this local service, the first officer in the other cases being an "architect," aided by some "opzichters," generally one in each division.

The general "waterstaat" service in Java is divided into five

sections. At their head there is a Chief Engineer who, in the first place, inspects and controls the local public works in the provinces in his division. Next to this, he has the supervision and execution of public works which are deemed of more general interest and which are so extensive or difficult that execution under the direct management of one or more engineers is necessary. Also, the designing of new works, the necessary surveying, and the preparation of the plans are under his guidance, and he is frequently consulted by the Residents and the Director of the Department, at Batavia.

According to the last official report, and deducting 4 engineers and 41 subordinates, who are employed in the outer possessions, and also deducting some vacant places, the staff of Java consisted of 60 engineers and 151 subordinates, of whom 6 engineers and 3 subordinates were at the head office at Batavia, 11 engineers and 98 subordinates were in the local public works, and 43 engineers and 50 subordinates were in the general service. Omitting some officers, who are employed on special tasks, above the ordinary establishment, from the engineers and subordinates of the general service, 9 and 21, respectively, are to be deducted who do not serve directly under the orders of the Chief Engineers in general service, but in the irrigation circles created afterward.

While the preparation of the projects of the greater irrigation works and their execution takes place under the control and supervision of the Chief Engineer, who is the head of the public works division, the closer management of the available water supplies suggested the idea of dividing Java into fourteen irrigation circles, each of which would contain the entire catchment basin of one or more rivers, without heeding the political frontiers of the provinces. An engineer who, with a proper staff, could be placed at the head of such a circle would be the natural adviser of the Residents and their officers of the civil service in those provinces, of which parts were included in the circle. In technical questions, a direct communication between the Director and the irrigation engineers was allowed.

When the provincial administration is taken into account, as ably described in the work of Mr. Day,* where the Resident is the

* Day, p. 417 *et seq.*

great center of the administration, it is obvious that the new wheel which was to be introduced into the machinery was to be managed with great care, and it was for different reasons that the experiment at first was only made with three of the circles, where the circumstances made it most needed.

These circles are:

1.—The Serayoe, in the provinces of Banjoemas and Kedoe (formerly Bagelen);

2.—The Brantas, spreading partly over the provinces of Soerabaya, Kediri and Pasoeroean;

3.—The Serang, being the basins of the Serang, Toentang and adjoining minor rivers in Samarang and a small part of Rembang.

The Irrigation Circle of the Serayoe.—This circle was at first established as an experiment in 1888, but after remodelling the construction it was made permanent in 1892. Attention was probably drawn to this part of Java, because the irrigation from the Singomerto main canal, which took water out of the Serayoe near the eastern frontier of Banjoemas, led to the construction of distributaries with several falls, escapes, aqueducts, and other works, while canals from other rivers intermingled with them. When, after much trouble, the system was made tolerably complete, it was seen that no arbitrary construction of dams by natives, or drawing of water at the wrong places, could be tolerated; and, where at first only the achievement of an irrigation work was contemplated, it was observed, as in other cases, that the work once attained could not stop at that, and that its advantages would be lost if there were no supervision. It was decreed, therefore:

"That within the said irrigation circle the maintenance of the distributaries and their works of art, as well as the distribution of the water from the canals, as far as this, according to the officers of the civil service, could not be left to the care of the villages, should come under the daily management and supervision of an engineer of the first or second grade, who will in all matters of irrigation be subordinate to the orders of the Resident of the involved province."

The delicate relation between the engineer, head of the irrigation circle, and the Resident, was arranged in detail by a written order which has proved a successful solution.

The Irrigation Circle Brantas.—This circle was established in

1892 as an experiment, after the model of the former, but its scope is much larger, and a great many interests of European manufacturers are here involved. The gross area is not less than 6 000 sq. miles, and that of the cultivated fields 850 000 acres, while 81 of the 188 sugar mills and 22 of the 46 indigo factories lie within its limits. It was necessary for the engineer who first took the management in hand to use a great deal of diplomacy in order to reconcile adverse interests and obtain effective results. In studying the works in detail, it was found that a great many improvements could be planned and executed and, what was of the greatest value, the irrigation canals were thoroughly surveyed and comprehensive maps on a large scale were made. These maps, of which copies are at the disposal of certain buyers, were much appreciated by the great manufacturers, who now could make out how, where and when the water for their crops was to be had.

A large staff, especially of native officers, was necessary for the improvement of the canals and other works, the making of the maps and the distribution of the water, but the importance of this was realized to such an extent, that since then the owners of factories have offered a large yearly sum to contribute to the efficient working of the system. Nevertheless, the expenses of this irrigation circle are not inconsiderable, and this, perhaps, prevented the Government from making the arrangement permanent. It was only in 1901* that this circle was put on the same permanent footing as that of the Serayoe. The European staff consists of 6 engineers of different grades and 15 "opzichters," whose aggregate pay and indemnity for traveling and other expenses are to be reckoned at $35 000 a year. Again, there are about $15 000 for the service of the Lengkong works and 30 native officers will aid in the water distribution, the number of which will be gradually increased by 5 a year, until the limit of 50 is reached. Their aggregate pay will be $13 320 a year as a maximum. For the ordinary maintenance of the works (repairs and new works excluded) is provided a sum of about $24 000, in addition to the compulsory labor ("heerendienst") of 985 000 day-tasks. Moreover, the factories pay voluntarily 34.5 cents per acre of cultivated area. A recent proposition to make this contribution coercive meets much opposition. The

* State paper No. 79, of 1901.

aggregate ordinary Government expense of more than $80 000 must be considered as a yearly contribution to the general welfare of the country.

The Irrigation Circle of the Serang.—The third irrigation circle, including especially the Demak water-works, is still in the period of experiment, and is an instance of a specific dealing with irrigation interests, which originated in the peculiar character of the country and the people. In this circle are also included some tracts in the former province of Japara, where sugar factories made European supervision desirable, but the principal section of the circle, the plain of Demak, has no such industries. In this circle is found an example of the intermeddling of the officers, European and native, with the methods of cultivation used by small peasants, which makes it doubtful whether the best way has been chosen.

In the former paragraph it has been mentioned that the available water supply is but scanty in comparison with the cultivated area. In order to make the distribution as just as possible, a very minute plan of "irrigation by turns" has been devised, and this, in the native language, is designated by the name of "golongan" system. In this system the fields are divided into four, five or six classes; those of the second class get the water a week later than those of the first; those of the third a fortnight later, and so on.

If the available supply is scanty and the first tilling needs a large watering, the maximum supply is not wanted for the whole area at once, but the last fields are tilled, as those of the first classes, or "golongans," do not require the water to such a great extent. At the same time, when the crop in the first is already mature, that in the last golongan can still get some water. In this system the peasant is no longer free to begin his labor when he pleases. In Demak the matter is pushed to such an extent that a native who does not begin the tillage of his land at the time officially decreed, incurs a fine, and, by non-paying, penal punishment.

Another feature of this system is the supervision, not only of the main canals and the secondary distributaries, but also of the tertiary ones, which bring the water directly on the fields, the canals which in British India are generally designed as village watercourses. The system is based on partition according to the cultivated area

taking water from the same canal. Measurements are used only to ascertain the proper division.

It seems that the results of the Demak system, which goes so far into details, are not yet deemed sufficiently obvious to the Government, for the permanent institution of this irrigation circle has not yet been authorized.

The system of irrigating by turns, or by divisions, has also been introduced into other parts, as in the Pategoewan and Pekalen districts, but in the former the area is divided into tracts of nearly 350 acres and the management of the water allotted to such a tract is left to a board of natives whose interests are involved, a system which seems to be well adapted to teaching them self-government and to maintaining a healthy interest in the arrangements, while the officials are not overburdened with petty affairs.

The management of the irrigation works, outside the three irrigation circles, has, in some instances, been arranged by the Government, when the different managers of the sugar mills were at variance with each other. The oldest example is the regulation of the water distribution from the Goeng and Koemissik Rivers in Tegal (now a part of Pekalongan). Here, some 18 years ago, when the cane fields were extended, arose such a strife among the owners of some eight factories, that the Resident thought it advisable to place the water distribution under one control, by engaging a staff of officials who should be paid by the managers of the sugar factories at the rate of about 60 cents per acre of cultivated area. Though in this way the mutual dissensions subsided, the interests of the native crops were disregarded to too great an extent, and the Government has finally placed an "opzichter" with some native officials at the head of this distribution service, and levies a sum of $3 200 from the factories, which is paid to the treasury.

This example is followed at the Pekalen works, and may be considered as a pattern for establishing the other irrigation circles, but a quick advance in this line does not seem to be now under consideration.

VII. Outlay and Financial Results.

The reason the Government is not eager to spend much money on the extension of the technical supervision of all irrigation works by taking in hand different matters now arranged by the native

officials or the villages themselves, may be due to the fact that, from a fiscal point of view, the urgency of the expense is not obvious. In Java no net balance is made of the general profits derived from the construction and proper management of irrigation works. While in British India from the greater works capital accounts are kept and the direct profits are given in percentage of the capital outlay, such is not done in Java. The cause is certainly to be found in the prominent part taken by the wet rice culture in the planting of the ground. This culture cannot be carried on permanently without a profuse supply of water. According to the fertility of the soil, the land tax is assessed in a certain ratio to the average quantity of the crop. When the water fails, a remission on the tax is allowed, but, when, by a more regular supply, the crop is better and larger, the tax is not increased at once, for an equitable rate of increase is difficult to ascertain. The peasant himself can make no estimate of how much better off he will be if his field, which until now has mostly depended on rain and a scanty allowance of irrigation water, gets a full supply. The paying of an additional water rate, therefore, is practically impossible. That a full supply allows of sowing earlier and planting a better sort of rice is a certain fact, but the idea, that an increased water supply gives an increased crop in the right ratio, is of an Utopian kind, and is only rooted in the minds of those fervid advocates of irrigation who shut their eyes to the facts. One of these is that in different provinces of Java different quantities of "paddy"* are regarded as a good crop. A very curious diagram of the relative fertility of different districts was published by the late Mr. K. F. Holle, a distinguished agriculturist.† From this it is inferred that the highest produce, averaging 65 and 70 picols of "paddy" per "bouw" (1.75 acre) was obtained in a part of Pasoeroean. In other provinces, Bantam, Banjoemas and Kedoe, this average is from 40 to 45 picols and in Japara, Cheribon, Tegal, Rembang and Madioen, from 25 to 35 picols is considered as a good crop.‡

At one time 70 picols per "bouw" was held to be a normal figure everywhere obtainable by irrigation, but, though the data from which the diagram was derived are not of the utmost trustworthiness, ex-

* Rice in the husk, weighing nearly twice as much as the rice that it contains.
† "Tijdschrift voor Nijverheid en Landbouw in Ned. Indië." 1882, p. 308.
‡ 1 picol = 138 lb.; therefore, 70 picols per "bouw" is 5 500 lb. per acre, and 25 picols per "bouw" is only 2 000 lb. per acre.

perience does not make it probable that everywhere such a large crop is possible. An advance of 20%, under favorable circumstances, in many cases, seems to be nearer to the truth.

To get an account of the sums spent in the last years for preparing and executing irrigation works, the Reports of the Indian Public Works can be consulted. According to the latest available, that of December, 1901, the sums shown in Table 5 were spent for different great works begun during the last 10 years. In this table Dutch money is converted at the rate of 10 guilders = $4.00.

TABLE 5.

Works and Province.	Irrigated area, in acres.	Sums spent in 1901.	Sums Spent from the Beginning until December, 1901, for: Surveying.	Execution.	Total.
Preanger Regencies.					
1. Tjihea works	15 000	$38 396	$20 847	$319 356	$340 203
Cheribon.					
2. Indramayoe irrigation	65 600	14 188	39 955	501 923	541 878
Pekalongan.					
3. Kaboeyoetan and Babakan works	35 500	21 760	124 098	433 292	1 302 348
4. Pamali works	80 000	93 527		543 430	
5. Waloe works	47 000	50 062		161 873	
6. Ramboet irrigation	21 500	36 270		39 655	
7. Tjiomal and Pekalongan	43 500	......	44 924	85 720	130 644
Samarang.					
8. Wedoeng irrigation and drainage district	28 700	30 072	1 903	504 479	506 382
9. Grogol and Singenkidoel irrigation and drainage district	28 000	33 870	19 212	164 851	184 063
10. East Samarang drainage district	12 200	13 842	16 129	292 466	308 595
Pasoeroean.					
11. Molek Canal, Senggoro district	10 500	18 303	4 708	24 472	29 180
Besoeki.					
12. Improvement Sampeyan irrigation	26 000	4 948	16 005	369 624	385 629
Banjoemas and Kedoe.					
13. Irrigation of Southern Banjoemas, Karanganjer and Serayoe Valley	227 500	1 828	96 492	597 008	693 500
14. Southern Bagelen, east of the Lokoeloe	100 000	32 897	154 010	216 070	370 080
Madioen.					
15. Irrigation in the Magetan and Ngawi districts	84 000	27 379	101 423	67 546	168 969
Kediri.					
16. Waroedjayeng-Kertosono scheme	43 600	61 400	24 828	55 791	80 619
Achieved in 1900:					
17. Pategoewan works (Pasoeroean)	15 800	......	17 065	325 485	342 550
18. Manggis Canal (Kedoe)	8 700	......	14 283	212 186	226 469
Totals	893 100	$478 742	$695 882	$4 916 227	$5 612 109

In Table 5 those works are entered which in 1891 were put on a working programme and those which afterward were found necessary, excluding the survey for works not yet begun and the Solo scheme which has not led to a satisfactory result. In order to ameliorate the irrigation of 893 100 acres, and partly to bring this ground under cultivation, a sum of more than $5 500 000 was spent in 10 years, or nearly $570 000 a year. As all these works are not completed, it is of no use to give the cost per acre.

Next to the major works, every year a certain sum is spent on minor works of local interest, and it is from these that the most direct profit is generally derived by saving labor on temporary works or warranting a regular supply. From 1895 forward particulars are given in the Public Works Reports. In that year, on 58 works, was spent a sum of $58 789, and $22 765 were spent on some of them before that time. In the following years more than 400 other works are named, and in the seven years, 1895-1901, it may be reckoned that 467 works cost $726 924, or a mean outlay of about $100 000 a year.

Adding to these figures $40 000 a year for surveying, the total irrigation outlay in the last years is $710 000 a year.

In the budget for 1904 an attempt is made to classify the works under the heads shown in Table 6.

This is more than the yearly average calculated previously, but the estimated sums are not always wholly spent.

On the total budget of Netherlands' India, prevised for 1904 at a grand total of $66 000 000, the irrigation expenses, even including the costs of maintenance and of the establishment, do not attain 2% of the total sum. No separate accounts are held, in order to pay part of the outlay from loans. Where the direct profits cannot be calculated easily, it is better to consider these works as contributing only to the general welfare in the same indirect way as new bridges, roads, buildings and the like. In that case, it is a wise policy for Java to construct them on a moderate scale and to pay them every year out of the actual receipts, and not burden the future with the interest on outlays which, as in the case of the Solo scheme, run the risk of being spent on a wrong principle or which afterward prove not directly remunerative.

TABLE 6.

A.—Productive works partly new and partly in execution (From which in the long run a rental on the outlay is expected)—

Pamali works (Pekalongan) (No. 4)	$24 800
Waroedjayeng and Kertosono (Kediri) (No. 16)	149 200
Bandjaran Canal (Banjoemas)	16 000
Molek Canal (Pasoeroean) (No. 11)	80 000
Tjiomal and Tjatjaban irrigation (Pekalongan)	140 000
Kedoengkandang Canal (Pasoeroean)	40 000
B.—Works of dubious productivity.—	
Improving the water distribution in the Sindopradja Canal System in Indramayoe (No. 2); in the tract east of the Tjiomal River (Pekalongan No. 7); in Southern Bagelen, east of the Lokoeloe River (No. 14); in the Magetan and Ngawi Districts (Madioen No. 15); improving the drainage of Singenkidoel and Grogol (Samarang No. 9); making a new embankment for the Toentang River (Samarang); and improving the drainage of the part of the Solo Valley called Bengawan Djero, together prevised in 1904 for	274 000
C.—Improvements and minor works	160 000
D.—Surveying and preparing of schemes	40 000
Grand total prevised for 1904	$924 000

For Java, the greatest benefit will generally be derived from minor works, useful in a limited sphere. A comparison with British India must fail, for in that country the failure of the rainfall may be so great that on a large area the crop is lost altogether. Famines, then, seem to be almost inevitable, and protective works to take water from perennial streams can and may be constructed on a large scale, for the sake of humanity and in order to reduce the expenses for relief in times of calamity. In most parts of Java scarcity occurs seldom; the water is generally easily taken from the rivers, and, where this is not the case, great works in case of emergency will be of no great value, for, if the rain fails, the supply of the streams will be also very small.

The policy of promoting the construction of permanent works, which relieve the natives from labor and risk, and especially the control of the equitable distribution of the water, seems the safest and best. This can be combined with helping the agriculturists with good advice, credit, abolition of compulsory services for public works, remission of taxes, etc.; for, as long as the petty peasants form the bulk of the nation the welfare of the country will be promoted best by improving their condition.

The general views of the Government and public opinion tend now in that way, but great care must be taken that so-called good measures, or those which are deemed perfect in the offices, are not enforced. To make the native people happy and prosperous under European rule, training in self-help must not be forgotten.

APPENDIX.

Explanation of Plates and Engineering Details.

*Plate I.—Map of Java, with Lines of Equal Rainfall.**—For the reduction to English measures 1 m. is taken roughly as 40 in. The geographical length and breadth grades are only approximately true, because the map is intended merely as a sketch. The great mountain ranges are nearly coincident with the lines of heaviest rainfall.

Plate II.—Vertical Fall at Tjiboeloe, West Canal (Buitenzorg). Fig. 1 on this plate is a view of a modern vertical fall with cistern, constructed in the West Canal at no great distance from Buitenzorg. In this arrangement no great round pit is formed in the canal bed down stream from the fall, but the apron, in works of this kind, is sometimes damaged.

Fig. 2 on this plate is a photograph of the escape made for the Tji Djambé Brook. The construction of the tunnel vault in brick and mortar and the rubble stone masonry of the wing walls can be distinguished clearly, with some typical workmen, Javanese masons, menials or traymen. The longitudinal section of this work is shown on Plate III, Fig. 4.

Plate III.—Tjihea Irrigation Works.—The upper portion of the canal taking water from the Tjisokkan, a tributary of the Tjitaroem and irrigating the Tjihea plain in the Preanger Regencies is shown in this plate. The fall of the river is very great and the bed is very deep between the rocky banks. The main canal had to be carried in the steep slope of the latter. Where this could not be managed by open cuttings, tunnels were used. The drainage of the hills was made across it, as in the case of the Tji Djambé, just at the end of the third tunnel.

When the work was begun, it was understood that between the first and second tunnels there should be an open cut, but as the banks, consisting of a sort of semi-rocky material, called "wadas" were apt to slip, it was necessary to lengthen the masonry of the covered tunnel until the open space was reduced to a mere pit. The water of the river is dammed by a low weir and enters the two gates of the intake sluice, whence it is admitted to the tunnel by lifting the shutters. It flows then in an open space before the tunnel entrance.

The tunnel section is of the same pattern as the Verdon Canal, in France. The stiff clay had to be timbered with wooden frames and planks, taken from the trees of the surrounding forest. The area of the wet section of the tunnel is 46 sq. ft.; the velocity of the current admitted to the masonry tunnels is 5.75 ft. per sec.

* Taken from a rain chart published in the "Tijdschrift van het Koninklijk Nederlandsch Aardrijkskundig Genootschap," 1900, p. 585.

The slope in the tunnels is 7.5 ft. per mile. In the open canal the slope is reduced to 1 ft. 8 in. per mile. The normal velocity in the earthen canal down stream is 2.5 ft. per sec.

The drawings are taken from a paper* by Mr. Elenbaas, the executive engineer.

Plate IV.—Map of Distributaries.—This is a general map of the irrigated blocks of the Pategoewan system in the Pasoeroean Residency, on the frontier of Soerabaya. The water is here derived from various small rivers which supply four main canals. The Pategoewan main canal takes it from the river of that name at Winong and runs along almost a contour line of the hilly country. The same is lower down in the case of the Bekatjak Canal, taking water from the Kedoeng Larangan. The two other main canals, *viz.*, of Kepoeloengan, taking water from the Pategoewan River on a lower point; and the Tanggoel Canal, taking water from the Djogonalan, which, lower down, is called Kedoeng Larangan, run nearly in the direction of the heaviest slope. The four canals provide water for 5 000, 6 900, 610 and 1 900 acres, respectively. The Pategoewan and Bekatjak Canals, respectively, 2 and 7.4 miles long, with supplies of 143 and 175 cu. ft. per sec., have no greater slope than is required for the regular flow of the water. The Kapoeloengan and Tanggoel Canals, respectively, 2.5 and 3 miles long, with 22 and 56 cu. ft. per sec., have a total fall of 204 and 194 ft., and had to be made as a flight of stairs, with short horizontal reaches divided by falls.

Every canal has secondary branches watering the blocks indicated on the map, and the surplus water is drained by separate drainage canals and river beds. Among the drainage canals, attention is called especially to the short-cut of Ketjelleng, by which the water of the Wangi River, derived from the small rivers, Kedondong and Komissik, is turned into the Djogonalan above the weir of the Tanggoel irrigation. Another short-cut is made near Kepoeloengan to throw the surplus water of the Pategoewan River into the bed of the Kambeng, which lies some 60 ft. deeper, in order to draw it off to the Porrong River by means of the new Kambeng Drainage Canal.

The weirs made for the Kapoeloengan and Bekatjak Canals are of older date, and have the ogee form, while the Tanggoel weir is of the vertical kind with a cistern. The head sluice at Winong took water without damming the river. Afterward, in that place, a low dam or sill was placed across the river.

The distributaries received primarily a capacity according to the area under command, *viz.,* the main canals 1 cu. ft. per sec. for every 33 acres, the secondary canals 1 cu. ft. per sec. for every 24.75

* *Tijdschrift van het Koninklijk Instituut van Ingenieurs*, 1893–1894.

acres and the tertiary canals or watercourses 1 cu. ft. per sec. for every 16.5 acres. Afterward this duty of the water was made different, varying with the extension of the blocks. Canals which water about 50 acres now get water according to the last-named scale, *i. e.,* 3 cu. ft. per sec. Blocks of 1 750 acres get a supply according to the greatest duty, *i. e.,* 52.5 cu. ft. per sec., and aggregate blocks of greater extent get 1 cu. ft. per sec. for every 40 acres. In the latter case it is reckoned that at least one-fifth of the area is occupied by sugar cane, and requires no irrigation in the rainy season. It must be remembered that in still larger territories in other parts of Java, where the ground is stiff clay, a duty of 1 cu. ft. per sec. for 50 or even 60 acres is deemed sufficient.*

Plate V.—Movable Weir at Lengkong.—This shows the location, a cross-section and plan of a single opening of the great movable weir at Lengkong on the Porrong branch of the Brantas River, and needs no further explanation. As one of the greatest, oldest and most remarkable works, it will be of interest.

Plate VI.—Movable Weir at Lengkong.—The two photographs on the plate give a general idea of the actual aspect of the works at Lengkong. Fig. 1 shows a ship-gate being brought into position; Fig. 2 shows the ship-gates floating after back-water has been obtained by putting sleepers in the down-stream grooves.

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*In Lower Egypt 1 cu. m. per sec. in summer will suffice for 2 150 acres of rice (Willcocks, "Egyptian Irrigation," second edition, 1899, p. 365). As 1 cu. m. = 35.25 cu. ft., this gives 1 cu. ft. per sec. per 61 acres.

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IRRIGATION.

IRRIGATION IN THE UNITED STATES.

By Elwood Mead,* M. Am. Soc. C. E.

Introduction.

Irrigation is a many-sided subject. The location, designing, and construction of canals, dams, head-gates, flumes, waste-ways, and measuring boxes belong to its engineering side. Preparing land for irrigation, determining the quantity of water needed by different crops and the best methods of applying it, are among its agricultural problems. Questions of water ownership, methods of establishing and acquiring titles to streams, the social and business relations of water users to each other, are among its legal and economic features. All these have a vital influence on the value of irrigation properties and on the peace and prosperity of irrigation communities. All need to be dealt with in order to reach a correct understanding of the present condition of irrigation development in the United States.

When the arid lands along western streams began to be reclaimed

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by irrigation, engineering problems were the ones most considered. The farmer who built his own ditch found the task so difficult that he had little time or inclination to think of anything else. Investors in irrigation projects asked about the land, the water supply and the cost of construction, and acted on the replies received. The importance of stable titles to water, the need of having rights to rivers defined and protected in times of scarcity, was at the outset disregarded. The future growth of irrigation and the controversies over water, which would come with this growth, were not foreseen. As long as there was water enough for all, one right was as good as another, and it was not until there were more ditches than there was water to fill that men began to realize that drought was possible under canals as well as in regions which depend on the clouds. Experience showed that, no matter how small the cost of a canal, it was invariably a losing investment if another canal higher up stole the water which belonged to it.

This tendency to magnify the construction side of irrigation is still manifest. While we may not give too much attention to problems connected with dam and canal building, we fail to give enough to those connected with the agricultural and economic sides. It is the work of the farmer which, after all, determines the value of irrigation properties. Few understand the outlay required to prepare wild land for the distribution of water and how important it is that the right method of application be adopted. The financial failure of many meritorious projects has been due to not realizing the expense which farmers must incur in grading land, removing sage brush, filling up gopher holes, and building checks, dikes and furrows for applying water to crops. It is this expense which delays reclamation and reduces returns from water rentals. This expense has been increased by much of the earlier work being done in a mistaken fashion. The waste of water and loss of money and time, in the aggregate, represents an enormous sum.

The evolution of irrigation in a valley or in a State is much like that of a railway system. The first problems confronting railway builders are to locate the line, secure the right of way, determine the grades and build the bridges and stations; but, when the road has been built, new questions arise, and these later questions are the ones which ultimately fix the value of the property. Combinations

must be made with other lines, and rates must be fixed so as to secure traffic and at the same time pay expenses. Also, in irrigation, construction problems come first, agricultural and economic ones later, but they are the problems of enduring importance. The water supply of a canal depends as much on the method by which rival head-gates are regulated as on the quantity of water which comes from the snows. The number of customers and the rates which may be charged for water do not depend entirely on the acres of land to be served or its productiveness. Misfit water contracts, arbitrary laws for fixing rates, the attempt to force a unit of water measurement on farmers which they did not understand and of which they were afraid, have bankrupted many western irrigation companies, where the land was fertile and the water supply abundant. A canal is a carrier of water, and the contentment of the community it serves depends on the efficiency of its arrangements for securing and delivering its goods. Head-gates must be adjusted so that each canal will receive its share of the stream, while each farmer should be as certain of obtaining his share of the water supply as the shipper on a railway is that goods consigned to it will go to their destination.

Extent and Value of Irrigation.

According to the report of the United States Census made in 1902, about 10 000 000 acres of land in the United States are now being irrigated. Of this, 600 000 acres are in the rice fields along the Atlantic and Gulf Coasts, 400 000 acres in the semi-arid region, and 6 000 acres in the humid States. The remainder is in the arid region. To reach this land, 59 243 miles of main canals and ditches have been built, or more than enough to extend twice around the earth, while the laterals leading from these canals to the fields represent an aggregate length of many times this distance. The difficulty of reaching remote and inaccessible regions, the indifference of settlers in these sections to letters of inquiry, and the absence of any official records in many of the States, render it impossible to secure complete statistical records, and make it certain that these figures are less than the reality. Since this report was prepared, progress has been rapid, and there must be now in the United States 150 000 irrigated farms, for which the canals and

reservoirs furnishing the water supply have cost on the average $10 an acre, while the expense of preparing land to receive water and building the laterals and furrows for its application has required an additional outlay of the same amount. It is a conservative estimate, therefore, to say that $200 000 000 has been expended in irrigation development, and it is certain that the values created by this development represent many times that sum. The rights to water in Colorado alone are estimated to be worth $90 000 000, and they are increasing every year.

Nothing connected with the industrial development of the arid region in the last ten years has been more significant than the increasing value of water. The greater demand by cities and towns for water for industrial and domestic purposes, the opportunities for its utilization in power made possible by the improvements in electrical transmission, and the greater value of water in irrigation, have all contributed to this result.

Some of the recent sales of water illustrate the enormous rise in its value as a commodity. The right to use the water of a spring in California, which supplies 50 miner's in. (1 cu. ft. per sec.), recently sold for $50 000. This did not include a yard of ditch, an acre of land, or any other form of property save the water. A right in the Arkansas River, acquired in the irrigation of a farm of less than 100 acres, recently sold for $225 000. In the early days of the settlement of Utah, Brigham Young bought all the rights to City Creek for $500. This stream is now one of the principal sources of water supply for Salt Lake City and the estimated value of this water right is $1 600 000. It is certain that, as population increases, the extensive and intensive use of water will keep pace with it, and the struggle over its use and control be augmented in like measure.

The irrigated lands which now sell for from $100 to $1 000 an acre would be practically worthless, without irrigation, and what is true of the country is equally true of the cities. Denver, Salt Lake City, and Los Angeles are as much the creation of irrigation as the orchards and farms which surround them. If the health and pleasure seekers, who now fill transcontinental trains, had to pass through continuous desert wastes and in the end dwell among the disagreeable surroundings of aridity, instead of among the flowers,

the gardens, fruit, and foliage which surround nearly every large city of the arid region, these trains would be empty, and the men of wealth and energy, who now find this section of the country the most productive place to engage in business enterprises, would have gone elsewhere.

The rapidity with which this change has been wrought is without a parallel in the development of any other irrigated country in the world, and, in addition, it has several unique features. These results have been accomplished in large part by men of limited means, and almost entirely by private initiative and enterprises, working without public subsidies or any form of public aid. The greater part of the work has been done in sections remote from transportation facilities, where labor was scarce and high, and many kinds of construction material costly. Hundreds of these ditches and canals were built without money to provide an equipment for doing the work in an efficient and economical manner. All these conditions have to be remembered in passing judgment on what has been achieved by engineers and farmers.

Some Features of Early Irrigation Construction.

The purpose of this paper is to describe some of the typical features of these irrigation works, the methods of applying water, and the social and legal institutions under which streams are distributed and used. In connection therewith, some significant features of irrigation progress in the United States for the past ten years will be pointed out, because this period is one of unusual importance, beginning as it does with the panic of 1893, which caused an almost complete stagnation in construction and settlement, and ending in the remarkable revival in both these directions growing out of the passage of the National Irrigation Act, in 1902, and the rising value of land and water which has rescued from seeming insolvency many canal companies and made it possible for private enterprise to engage in many new projects which hitherto could not be considered.

Some of the earlier phases in irrigation development which have a vital relation to the changes now taking place will be discussed briefly, because a knowledge of this evolution is necessary to an un-

derstanding of some of the most significant features of the present situation.

Although modern irrigation in the United States only dates back fifty years, its practice on this continent is older than historical records. The first Spanish explorers on the Rio Grande found the Indians of that valley watering the thirsty soil, as their forefathers had done for unnumbered generations before them, and as their descendants are doing to-day. In southern Colorado and northern Arizona and New Mexico are well-defined remains of irrigation works, of whose origin even tradition is silent.

Modern irrigation began with the settlement of Utah by the Mormons, with the planting of gardens by the Franciscan monks in California and with the simple furrows which turned streams on the low-lying bottom lands in the vicinity of the stage stations along the Overland trail. It was not, however, until about 1870, when the Greeley Colony in Colorado and the Anaheim Colony in California were founded, that the construction of irrigation ditches and canals began to invite the attention of capital, and projects took on a character and importance which made them an adequate field for the talents and training of the engineer; but, at the outset and for many years thereafter, the irrigation engineer was confronted by conditions which in many ways were unsatisfactory.

In order to design an irrigation canal properly, certain things need to be known. One is the duty of water. In designing the earlier canals, engineers had to guess at this. Sometimes the canals were made needlessly large, more often too small. The earthwork channel could be enlarged readily, but head-gates and flumes were not so easily modified.

At the outset there were no gaugings of streams, to determine how widely they fluctuated in a single season, and, what was of equal importance, to show the variation in supply from year to year. Even if there had been such gaugings, there was another element of uncertainty which has tormented the engineer and brought disaster to many investments. This is the absence of records showing how many canals divert the flow of a river, or the volume which each is entitled to take. When the Greeley Colony Canal was built, the total area irrigated from the Poudre did not exceed 1 000 acres, but the owners of this territory secured a grant of enough water

to irrigate 100 000 acres. Engineers could not anticipate this extravagance of judicial decrees and their effect on the available water supply.

There were certain influences which always operated to handicap engineers in making preliminary investigations. Outside of California and the lands lying within the railway grants, canal projects had to deal almost entirely with public lands. The laws for acquiring these lands were framed for the humid region, and were wholly unsuited to the requirements of irrigation. An engineer could estimate the acreage of land which a canal would cover, but it was beyond finite intelligence to determine how much of that land would be acquired under the public land laws by farmers, and how much by speculators who never had been farmers and never expected to become users of water. The building of a canal to reclaim a particular tract of public land enhanced its value. It made it certain that this land would in time be cultivated, and that its value as grazing land would be raised to the value of farming land. Every ditch survey, therefore, was the signal for a rush to the land office and for covering the whole area with speculative filings under the Homestead and Pre-emption Acts, under either of which men could acquire title with no residence, or only a brief nominal one, and without the cultivation or irrigation of a square foot of the land filed on. Having possession, these speculative entrymen could, by refusing to enter into water contracts, starve the ditch company into bankruptcy or force the purchase of their claims as a means of putting an end to the embargo on settlement.

Abuses of the land laws made the projectors of canals insist that preliminary surveys should be made as hastily and secretly as possible. Inadequate water laws gave added force to this desire. No one now questions the statement that rights to water are as valuable as titles to land, and that the granting of rights to streams should have been made as carefully as the public land is disposed of. If this had been done, nearly all the disastrous litigation and fully one-half the engineering mistakes connected with past canal building would have been averted. Instead of this, there was no supervision over the filing of claims to water, and many recorded were so inaccurate and misleading as to be practically worthless.

The importance of priorities, the uncertainty as to what rival

enterprises would claim, and the tendency of rival mushroom corporations to spring up whenever a legitimate project was started, made investors desire preliminary surveys to be made with a rush. All they wanted was the necessary description of the canal line in order to make a filing.

The Highline Canal in Colorado is 60 miles long. At the upper end is a tunnel through a mountain; at the mouth of the tunnel, a precipitous cliff, half a mile long, on which a shelf for a flume had to be blasted; below that there were a number of torrential streams which the canal line had to cross. It was, at the time, the most difficult and costly project which had been undertaken in the West, yet the line was located and the estimate made from a field reconnaissance which lasted only three days. The fact that the ultimate cost was within a few thousand dollars of this estimate showed the remarkable intuitive engineering ability of Mr. E. S. Nettleton, the pioneer irrigation engineer of the Rocky Mountain region.

Few engineers possess this faculty in equal degree, and, in many instances, the results were far different. The estimated cost of the canals projected originally by the Greeley Colony was $20 000. They cost more than $400 000, yet the acreage cost of water under these canals is far below the average.

Eastern engineers were especially likely to make errors in estimates based on these hasty surveys, because the behavior of earth and the expense of moving it is so different in the arid region from that in the Eastern States. The indurated clay of many Western States can be moved readily with plows and scrapers when it has been thoroughly moistened, but it has to be blasted when dried out in midsummer. In spring it would be classified as earth, in August as solid rock.

In every one of the Western States there was a period of speculative development and a rush to acquire control of the waters of a river by the establishment of a prior right thereto. During this period, it was the investor rather than the engineer who insisted on neglect of necessary preliminary studies, and it was the investor rather than the engineer who entered into agreements which made construction costs needlessly expensive. The rush for an early water right caused one canal in Colorado to be dug in midwinter. Thousands of yards of frozen ground had to be blasted, when a few

weeks later it could have been moved readily with plows and scrapers. After the canal was completed, it remained practically unused for ten years because of the delay in securing settlers.

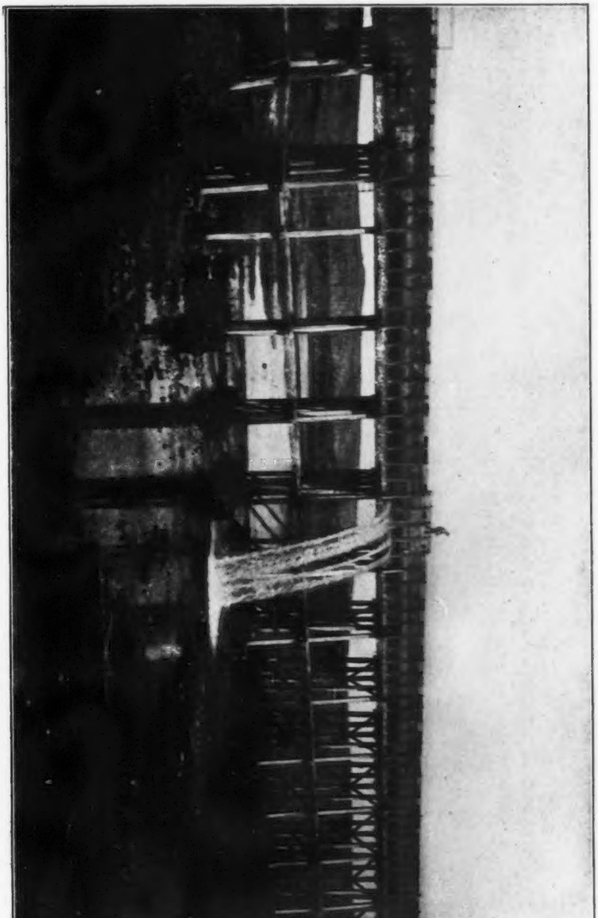
Many of the large canal projects were promoted by men without means, but having access to capital in the East. The basis of their operations was usually a preliminary survey and a filing on the water of the stream. As a rule, they had little money to pay for surveys and little real interest in the accuracy of estimates, because it was not their own money but the money of someone else which would ultimately be risked. In nearly every instance, pressure was brought on the engineer to reduce the estimated cost. Men who were absolutely honest seemed to think that it was not natural conditions but the fiat of the engineer which determined the outlay, and an estimate which threatened to make the bait unattractive to the investor was regarded as an evidence of unfriendliness on the part of the engineer and treated as a personal grievance. Many conscientious engineers lost their employment because of refusal to sacrifice their judgment to that of the promoter, and many other honest but weak engineers were influenced to modify their judgment by the arguments and influence of the promoter. The result was that in many cases projects were begun with only half enough money to complete them, work would be suspended before water could be furnished, settlers depending on the canal would undergo a period of great hardship and suffering, and too often the original investment would have to be sacrificed.

When it came to construction, the engineer had to depart from the engineering practice on irrigation works of other countries. When the first canals in Utah were built, nails and bolts had to be hauled more than a thousand miles in wagons through a hostile Indian country without roads or bridges. Every pound of iron used cost more than $1, and, therefore, it was used sparingly. The air compressor used in the tunnel of the Montezuma Canal in Colorado had to be hauled 50 miles over a mountain range on a road where either snow or mud made travel almost impossible. This freight bill cost more than the machinery delivered at the nearest railway station. The plows and scrapers used on canals in northern Wyoming had to be hauled 275 miles across a country without roads or bridges, that being the distance to the nearest railway station.

The three materials which were abundant and cheap were lumber, earth, and loose rock, and the extent to which these have been used constitutes the characteristic feature of American irrigation engineering. We have the highest earthen dams in the world. Many of the loose rock dams built were bold innovations on existing practice. Where masonry was used, the desire to reduce cost has led to some novel structures, the Bear Valley Dam, in southern California, being perhaps the most conspicuous. This dam has no parallel elsewhere. It is 64 ft. high and its foundation is 20 ft. wide. It is 2.5 ft. thick on top, and 8.5 ft. thick 48 ft. below. Its ability to resist water pressure, therefore, depends entirely on its arched form. The reason for this bold innovation was the cost of material. The price of cement delivered on the ground was from $14 to $15 a barrel. The masonry is reported to have cost $22 per cu. yd.

When the West Side Canal, in northern Colorado, was built, lumber could be had at $10 per 1 000 ft. delivered where needed. Cement cost $10 a barrel. The use of masonry was deferred. When the Bear River Canal, in Utah, was constructed, lumber cost $20 per 1 000 ft., delivered along the line. The few masonry structures erected cost from $9 to $12 per cu. yd. The result was that lumber was bought by the million feet and cement by the hundred barrels. Many of the timber structures, however, had to be replaced in 7 years, all of them within a dozen years, and when replaced the increased value of lumber and the cheapened cost of concrete made a reversal in the original selection of material. One of the most interesting problems which now confronts the American irrigation engineer is to determine how far cement and concrete can be used with economy in replacing wooden structures on old canals, and how far he can avoid the use of wood in building new ones.

In certain sections of the country, the engineer has been able to work under better conditions. In California the greater part of the land to be irrigated was owned by the men who provided the money for canals. The necessity for secrecy and haste in making preliminary surveys did not exist here. The same has been true of a number of projects carried out within the land grants of the transcontinental railroads. It explains why Colorado has more irrigated land than any other State. The Union Pacific land grant



TYPE OF HIGH WOODEN FLUME.

extended along the South Platte and one of its principal tributaries. Its lands could be acquired by canal builders who were thus freed from the vicissitudes of the misfit public land laws. The State lands were also located along the lines of projected canals, and speculative filings on these lands in this way were forestalled. In every State where the irrigator has had to deal with the public land laws, they have proven a handicap to the rational and economical extension of irrigation.

Reviewing conditions as they existed in 1893, when progress under the old order of things came practically to a standstill, it may be said that the irrigation engineer can rightly claim credit for the cheapness of the work done under his direction. With all the handicaps of high freight rates and high prices for both labor and supplies, the average cost of water was less than $10 an acre, probably not more than $8 an acre, many of the early water rights having sold for from $3 to $5 an acre.

The extended use of wood in the early canals, while it will not continue, cannot be considered a mistake, under the conditions which prevailed. There are some defects, however, in American irrigation canals. Too many canals simply follow contour lines, no attention being paid to the sharpness or the number of the bends. These canals have always been troublesome to operate, and large outlays for reconstruction are inevitable. Another objectionable tendency has been to make canals too broad and shallow. The argument in favor of this was that contracts for excavation could be made at a better price per yard and water was more easily taken out of such canals. However, there is an enormous increase in loss from seepage and evaporation and greater tendency to silt up. Few of the earlier canals were planned to carry more than 3 ft. of water. Several which have a bottom width of 50 ft. originally carried water to a depth of only 2 ft., being patterned, apparently, after the rivers from which they were diverted.

The Beginnings of Irrigation Practice.

Probably two-thirds of the land now irrigated was brought under cultivation by men who had no previous knowledge of irrigation. They knew nothing as to the quantity of water required to grow

crops or the methods of preparing land for its application. They did not appreciate the fact that irrigation is a co-operative industry and the individual cannot act independently, because irrigators are bound together by their common tie of dependence on the canal and the stream. Nearly all these farmers objected to following corporation methods in organizing their enterprises and would not submit to needful regulations and restraint in their management. These inherited ideas and tendencies caused much of the controversy and litigation which have beset farmers in the valleys of the arid region. Every irrigator insisted on raising his head-gate when he pleased and shutting it when he ceased to need water. As a result, in dry weather the crops of the farmers at the lower ends of canals were burned up by drought, while in rainy seasons they were flooded. When the ditch management did not regulate the head-gates, the farmer at the lower end of the canal made it his personal business, and, when persuasion would not secure a fair division, the shovel became an instrument of war as well as an implement of peace.

The farmer who knew nothing of irrigation faced a perplexing situation when beginning its practice in the West, and this was especially true in the early years of settlement. If he built his own canal, he did it without knowing how many ditches had superior rights, or how much his share would be in the final lottery of litigation which inevitably lay before him. If he purchased a water right from a canal company, he was equally uncertain about the priority and value of this company's water title. In addition, many of the early water-right contracts were notoriously unfair. They required the irrigator to pay the annual charge, whether or not he received water. They absolved the ditch company from all liability when it sold rights in a stream where the water supply had been exhausted by prior appropriators. The courts, in a number of recent instances, have declared these contracts illegal, holding that irrigation companies cannot compel payment for water rights where they are unable, either through lack of capacity in the canal or scarcity of supply in the stream, to supply the water sold.

Water-right contracts vary widely in their details, but they fall into three general classes:

1.—Where water is furnished at an annual rental;

2.—Where companies sell perpetual rights for a fixed sum, to which is added an annual charge for operating and maintenance expenses;

3.—Where the purchaser buys an interest in a canal and its water right, with or without a voice in the management of the company.

Eastern investors in irrigation works almost always favor furnishing water at an annual rental, because this is the plan pursued by municipal water companies in supplying domestic users. Human nature and the water laws of some Western States, however, have brought this plan into disfavor. An annual rental means an annual fixing of the rental charge and an annual contest over the rate, farmers desiring to have it as low as possible and the companies to have the charge maintained or increased. In this, the farmers are at an advantage. They are on the ground. Their votes give them a large local influence, while the canal company is often a foreign corporation and an object of local prejudice because of this. The political influence exercised by irrigators has led a number of the Western States to pass laws authorizing the supervisors or commissioners of counties to fix the rates at which water shall be supplied. In Colorado, the power of commissioners is absolute. In California, the courts have held that the rates must be reasonable, but the settlement of what is a reasonable rate is not always easy and is nearly always expensive. There have been instances where the rental rate fixed by county commissioners was so low that the water rentals would not pay operating expenses, to say nothing of interest on the investment, or maintenance and repairs. In one instance, the rate fixed by the commissioners was 20 cents an acre, while the operating expense alone was $1.20 an acre.

Objections to a rental charge have been particularly numerous where the charge was based on the acres irrigated. There has been less controversy where the charge was for the volume furnished. Under the acreage charge the tendency to waste water compels canal companies to make the rate high. Where the farmer pays for what he uses and gets the benefit of his saving, the increased skill and economy he exercises tends to lower the acreage rate without reducing the income of the canal company.

The most satisfactory plan is where the irrigator buys a share in the canal. Even if he does not acquire the right to an immediate

voice in its operation, the knowledge that this is to come in time makes him disposed to accept the situation without protest, even when the management is not in accordance with his views. Considering the question of water rights broadly, the prices charged by canal companies have been reasonable, frequently generous. In every irrigated district 20 years old, valid water rights are worth two or three times as much as the irrigators paid for them. The irrigator has also had the best of controversies over rates. Few canal enterprises have proven profitable where the returns depended on water rentals. It is only where the company owned the land and could reap the benefit of increased values that the returns from these enterprises have been satisfactory.

Progress of Irrigation Since 1893.

The panic of 1893 put an end to irrigation development for a time. Before its arrival canal building had outrun settlement, and there were large areas below ditches awaiting reclamation. This land under normal periods would have been acquired by farmers from the Eastern States, but times were hard in the East, these farmers lacked the money to establish themselves in a new country, and were unable to sell out where they were except at ruinous sacrifices. Financial conditions were but little better in many of the irrigated districts. Prices of farm products were low, and the profits of irrigation far less than they had been in the past. It was a trying period for owners of canals and one of discouragement and doubt for many irrigators struggling to improve their farms. During this depression thousands of acres of irrigated land with water rights attached sold for less than the actual cost of providing the water supply. Canal building in unsettled sections came to an end because the low prices of water rights left no margin of profit for large and costly projects. Substantial progress was made in some of the older districts, like the valleys of the South Platte and Arkansas, in Colorado, and Salt Lake Valley in Utah, where conditions were especially favorable for the growing of high-priced products and where irrigators had become exceptionally skilful in the use of water.

Reform of State Laws.

While these conditions brought great hardship, they were needed to bring about changes in legislation and methods which were required to provide a stable foundation for future development. The first of these was a betterment of State laws, for the settlement of titles to water, and to secure the just division of streams in times of scarcity. When the panic came there were only three States in which there was an adequate record of water rights or any officials to divide the supply among claimants. These were Colorado, Wyoming, and Nebraska. Since 1893, five other States—Nevada, Utah, Idaho, Montana, and South Dakota—have passed laws creating the office of State Engineer, and in three of these—Nevada, Utah, and Idaho—provision is made for comprehensive investigation by State authorities of the actual use of water as a prerequisite to the acquirement of rights to streams. In two other States—Oregon and Washington—commissions have been appointed to draft codes of water laws for submission to the next State legislatures. A commission, chosen by the Water and Forest Association of California, spent two years in making an investigation and preparing a report on this subject in that State. Its report included a draft of an act to provide for the public control of the public waters, but its recommendations were not accepted by the legislature.

Important as the material results of this legislation have been, they do not fully exhibit the gains which have been made. There is everywhere a better understanding of the necessity for public control of irrigation and popular opposition to the improvident giving away of streams to speculative appropriators which will inevitably lead to water monopoly in the future. Prior to 1890 the methods of acquiring title to water were substantially the same in all the Western States. They would have been farcical had the evil consequences not been so apparent. One way was to acquire a title by building a ditch and using water without any record or notice. The State never objected, and, if some individual did not interfere, the right became vested by prescription. Many of the rights were acquired in this fashion, the amount of the appropriation being determined by subsequent litigation. The usual plan was to file a claim to water in some office of record, usually the county clerk's office. This claim could designate any quantity of water and specify any use. The

claims were usually of the most indefinite and often grotesque character.* They were practically disregarded until such time as increased use caused a shortage. When controversies arose because of this they were settled by litigation. In Colorado and Wyoming there was provision for making all claimants to the water of a stream parties to this litigation, but in the settlement of such cases no one appeared except those claiming the property, the rights of the public were practically ignored, and it frequently happened that the rights granted were based upon the *ex parte* claims filed with the county clerk without regard to the quantity of water which was needed or which had been actually used. Even where attempts were made to restrict rights to actual necessities, the absence of measurements of the water used gave a wide field for surmise and conjecture on the part of interested witnesses, with the result that court decrees have granted water enough to cover the land to a depth of 1 ft. for the season in some cases and enough to cover it to a depth of 500 ft. in a season in others.

Except in Colorado and Wyoming, there was no provision prior to 1900 for the public to enforce economy in the use of water when it was scarce. The irrigator who found himself being robbed of water, by its unlawful or wasteful diversion above, had either to close down the offending head-gate by force or ask for an injunction by the courts. A canal owner in California was asked how he managed to protect his rights in the seasons of shortage; he replied that, in the first place, he had obtained a decision establishing his legal title to water, but that, in addition, every year he shipped in

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*The character of these claims to water has been well set forth in a report on irrigation from the Los Angeles River, Cal., by E. M. Boggs, Bulletin 100, Office of Experiment Stations, U. S. Department of Agriculture, from which the following is an extract:

"It is a matter of common knowledge that in general the posting of a notice at the place of intended diversion is farcical. Usually the posting is performed by attaching the paper to the rough bark of a convenient tree somewhere in the vicinity. Tacks or nails are not often provided, and substitutes are made of two or more twigs driven into knife punctures in the bark. Permanence of this notice is seldom deemed desirable and is less often secured. The wind may tear it from its insecure fastening a few minutes after being placed in position. If not destroyed bodily or blown away, the first rain may blur or the sun may fade its writing to illegibility. But what matter? By posting the notice and recording a copy thereof within ten days the claimant has complied with the law and has no further concern. If the public or any individual suffers through the insufficiency or the ephemeral character of the notice, that is not to be regarded as the claimant's fault but as the other man's misfortune. In very many cases a suitable tree not being at hand the notice is not displayed to view in a conspicuous place at all but is folded, laid upon a boulder or on the ground, and weighted down by a stone. It would require diligent search to bring to light all the notices which may be quietly reposing under stones in some of our mountain canyons.

"* * * Usually the facts set forth with the most particularity are those which are the most unnecessary because perfectly obvious, *viz.*, that the places are situated in Los Angeles County, Cal., and in many cases no more definite description is given. Numerous statements like the following are found: 'I claim the water where I now stand,' or 'where this notice is posted on a tree,' or 'in this canyon'."

two men from Arizona who were handy with a gun, and that between the courts and the guns he managed to get his share.

Claims to the same water supply are scattered along a number of Western rivers and their tributaries for more than 500 miles. They involve the diverse and conflicting interests of individuals, communities, and even different States. The great extent of territory embraced, and the constantly changing conditions with respect to the needs of irrigators, and the volume of the water supply make it impossible for each irrigator to protect his own rights. The farmer at the lower end of the valley cannot cultivate his fields and watch the head-gates above. As an individual, he is helpless. Peace and prosperity for the individual and the community alike depend upon public control of the streams and the enforcement of laws by men of experience and administrative ability of a high order. The greatest weakness of American irrigation has come from the failure to recognize this.

The Arkansas River will serve to illustrate the importance of the social and legal problems of irrigation. In Colorado this river is diverted by 1 900 ditches. Their aggregate length, exclusive of laterals, is more than 3 000 miles. About $9 000 000 have been expended in their construction. From them, 600 000 acres of land can be watered, and more than 400 000 acres are now being irrigated. Between 7 000 and 8 000 people depend on these ditches for their water supply, and they have invested large sums of money in the purchase of stock in the companies, in buying water-right contracts, or in the payment of annual water rentals. The value of the irrigable land thereunder is between $25 000 000 and $30 000 000. The cost of operating and maintaining these works is more than $200 000 a year. Each one of these 8 000 irrigators knows that in order to grow a crop he must have his part of the water of the river at the time the crop needs it, and that, if some other irrigator takes his share, his crops will be ruined, no matter how industrious or skilful he may be in their cultivation. Scattered over a territory more than 200 miles long and 50 miles wide, 8 000 irrigators, as individuals, cannot protect their own rights. Unless the head-gates of the 1 900 ditches are adjusted so that no gate can take more than its proper share, and unless those not entitled to water are closed entirely when the protection of superior rights requires it, there

must inevitably be injustice, bitterness of feeling, and failure of crops.

The final problem of irrigation becomes one of distribution, and, to make this a success, the arrangements for transporting water to the laterals of the different farms should be carried out with the same order and system that marks the management of a railroad or express company. The difficulty in doing this is increased by the fact that the volume of water to be divided is never uniform. It varies from day to day and from season to season. The flow of the Arkansas, for example, has been as high as 40 000 cu. ft. per sec. and as low as 100 cu. ft. per sec. At its highest stage, there was more water than all the canals could carry, and the integrity of head-gates was threatened. At its lowest stage, there was not enough to wet the flumes. Irrigation on this stream has already been extended so much that, without the storage of flood waters, the crops on many fields each year must be parched by drought, and great storage reservoirs have been built and others are contemplated in order that the 200 000 acres of land under existing ditches, not yet irrigated, may be brought under cultivation. The water of many of these reservoirs has to be turned into the river, mingled with that coming directly from the snows, and carried past the head-gates of many ditches and canals not entitled to stored water, in order to reach the head-gates of the canals under which its owners live.

The details of State administration, in the six States which have provided it, vary so greatly that no general statement can be made. The plan provided in the Wyoming code will serve to illustrate their general features. Under it, the water of canals, streams, springs, lakes, and ponds is made State property. The State Engineer is the president of a board of five men managing this property. The State gives irrigators free use of the water, permits for this being issued by the State Water Board, and it is a misdemeanor to take water without such a permit. To secure such a license, intending users of water must file a map and description to show the location of the proposed ditch or reservoir, and the land on which the water is to be used. Where a project will injure an existing right, permits are refused. After the water has been actually applied to the land the State issues a certificate of appropriation which describes the land to which the water is attached. These certificates of water are recorded in the same manner as land laws.

In order to protect these titles the State has to control the division of water when there is not enough for all. For this purpose the State is divided into 4 divisions and these are subdivided into 40 districts. Each district has a water commissioner, a State official acting under the direction of the State Engineer, and who in time of shortage raises and lowers the gates in such a manner as to give to each ditch its proper share. Head-gates adjusted by the commissioner may not be moved by the owner. The commissioner has authority to arrest offenders, or he can call on the sheriff to do so.

It is always difficult to induce irrigators to submit to this public control, but, once adopted, it is always maintained. It relieves irrigators from watching their neighbors. They do not have to patrol the stream at night to prevent gates being raised when they should be closed. Where irrigators have to defend their own rights neighbors are always at war. Where there is public control they live in friendly relations with each other, while the water commissioner is often abused. If he does his work with tact and justice, he becomes the most important member of a community and contributes to its respect for law and order and to the peace of mind and well being of the irrigators to a degree which has to be experienced to be understood.

The value of the work done by State Engineers, in gauging streams and ditches and measuring the areas irrigated, has become so manifest that the States are making liberal appropriations of money for the conduct of these offices. They are now gathering facts on which rights depend instead of leaving this to be done by ignorant or interested witnesses. In recent water-right adjudications in Utah and Idaho the State Engineers' offices made surveys to show the areas of land irrigated. The Idaho Supreme Court has recently affirmed the legality of this proceeding.

The Carey Act.

The first step toward a revival of canal building came in 1894, with the passage by Congress of what is popularly known as the Carey Act, which gives to each State the right to select 1 000 000 acres of land, provide works for its irrigation, and dispose of it to actual settlers and irrigators in tracts of 160 acres each. Under this act, the land to be watered by a particular project can be segregated by the State, and thus speculative land filings thereon are prevented.

This renders it possible to make adequate preliminary surveys and investigations. Engineers can take time to determine what the work will cost, whether there is an ample water supply, what the probable duty of the water will be, and what kind of water contract will come nearest to meeting the needs of settlers and be most in accord with local methods and prejudices.

The Congressional law was extremely indefinite. It left each State untrammeled as to its acceptance of the act or the methods to be followed in carrying it out. One or two States made the mistake of attempting to make money out of the act through charging a high price for the land. Wyoming was the leader among the States to enact a successful law. There, effort was directed toward framing a law which would attract irrigators. The land is sold for 50 cents an acre. Ditch builders are aided in surveys and investigations by the State Engineer's office. The Wyoming law was substantially copied by Idaho and in many of its features by Oregon. In these States a number of large projects were undertaken even in the period of depression; four are being carried out in Wyoming, and several are under way in Idaho.

Under these State laws, after the land to be reclaimed is segregated the water supply is gauged either by the State Engineer's office or by the United States Geological Survey. No one but an actual settler is permitted to file on the land. He is limited to 160 acres, and, in addition to the land filing, he must acquire a right in the canal sufficient to irrigate the land. The water right and the ownership of the canal go with the land irrigated. The State does not build the canal directly, but makes contracts with companies.

Canal companies have preferred to operate under this law for two reasons:

1.—It prevents speculative filing and insures the early reclamation of the land;

2.—It puts an end to litigation over water-right charges.

Settlers prefer projects carried out under this law for the following reasons:

1.—They acquire a right in the ditch as well as ownership of the land;

2.—They are relieved from anxiety as to a water supply, because of the preliminary investigations by the State;

3.—The land is sold at 50 cents an acre, while the Government charges $1.25 an acre for desert land;

4.—It insures all the land being acquired by cultivators instead of a large part being secured by non-resident speculators.

National and State Investigations.

Another important gain in the past ten years has been the information gathered by the State Engineers' offices and the scientific bureaus of the United States Government. In planning irrigation works, the engineer does not now have to depend upon surmise and conjecture regarding either the volume of the water supply or the acreage which a canal of given capacity will serve. More than ten years ago the United States Geological Survey began to make gaugings of the flow of streams used in irrigation, and since then, has made extensive measurements to determine the amount of both surface and subterranean water supplies. In addition, this bureau has made extended surveys to determine the location of irrigable areas and to obtain data regarding the possibilities and cost of water storage. These data have been valuable for those charged with the administration of State laws, and have proven of great practical value.

Following the inauguration of these studies of water resources have come investigations regarding the best means of applying water and the gathering of data regarding legal and economic conditions. In these the State experiment stations of the different arid States have taken a conspicuous part. Since 1897 this work has been carried on largely in co-operation with the irrigation and drainage studies of the Office of Experiment Stations of the United States Department of Agriculture, which also co-operates with the State irrigation authorities in making extended measurements to determine the duty of water, the best means of its application to crops, and collecting and publishing reports on the legal and economic conditions in the different States.

These measurements give an average duty of water, measured at the head-gate, of 4.2 acre-feet for each acre irrigated, and show that about one-half of this volume is lost during its transit through the canals by seepage and evaporation. They have also shown in a striking manner the need of a better understanding of the best methods

of preparing land for irrigation and applying water to crops. It is in these directions, perhaps, that the greatest waste and loss in land reclamation have occurred.

Because of their superior preliminary training, engineers soon discover the principles which should govern canal building in order to have them conform to the conditions and make the best use of the material at hand. Farmers have not been in a position to make equal progress. Their knowledge of methods, to a great extent, has been confined to what took place in their own neighborhoods, and, both as to this and the tools used, it has been as much a matter of accident as of intelligence whether or not these were best suited to their conditions.

The diversity of methods used is remarkable, and is due largely to the fact that irrigators have come from all parts of the world. The 150 000 men now applying water to crops include all classes and nationalities. Each settler from a foreign country, especially if it was an irrigated one, seeks to introduce on his farm the customs and practices of his old environment. This is particularly noticeable in California, where the Chinese irrigate their truck gardens in Chinese fashion; Italians, Spaniards, and Mexicans imitate, for a time at least, the ways of their forefathers; the farmer who comes from the Mississippi Valley seeks, wherever possible, to mix the old way of doing things with the new. As a result, there are now in use in the West about thirty different methods of applying water to crops. The really important ones, however, can be classified in four groups:

1.—*Flooding.*—Of the 10 000 000 acres now irrigated, it is probable that 6 000 000 acres are watered by flooding. Under this system, the ditches, which follow the contour of the country but with grade enough to cause the water to flow through them with considerable rapidity, are plowed through the fields at varying distances apart, from 60 to 300 ft. From these contour ditches the water is turned out to flow down the slope, being spread over the entire surface by the manipulations of the irrigator, who, equipped with rubber boots and a long-handled shovel, directs the course of the water from one lateral to another.

2.—*Furrow Irrigation.*—This system is used chiefly with cultivated crops. It is also used, however, in the irrigation of hay and

grain. Shallow furrows are marked down the slopes from 2 to 3 ft. apart, the intervening ground being moistened by percolation.

3.—*Checks.*—These are where the land is divided off into compartments by ridges, the bottom of each compartment being graded until it is level or approximately level. In size, the checks vary from a few hundred square feet on the farms of Mexicans to 40 acres on hay ranches in California.

4.—*Basins.*—These are confined to orchard irrigation. Here, the water is run down rows to fill a large basin around the body of each tree.

The average cost of preparing land for irrigation by these different methods is as follows, not including removal of sagebrush:

Flooding	from	\$2	to	\$5	per	acre.
Furrows	"	\$1	"	\$10	"	"
Checking	"	\$8	"	\$25	"	"
Basins	"	\$3	"	\$10	"	"

Each of these methods has many minor modifications, and each is suited to particular conditions and at the same time entirely unsuited to others. One of the most serious mistakes made by farmers is in the adoption of the wrong method. For example, on the Pacific Coast, checks and basins are used almost exclusively. Small farmers raising mixed crops would often find the flooding system superior. East of the Rocky Mountains, flooding is practiced nearly always where hay and grain are grown.

The Storage of Water.

Permits for 225 storage reservoirs were issued by the State Engineers of Colorado and Wyoming for the two years ending December 1st, 1900. Prior to 1890 there were few reservoirs outside of California. They are being built now because the growing of more valuable crops has raised the price of water and made storage profitable. Canyon Creek Reservoir, in Utah, cost \$85 000. In 1901 it cost \$500 to maintain it. The water was valued by its owners at \$50 000. The need for reservoirs became imperative when wheat growing gave way to diversified farming. Alfalfa, potatoes, and sugar beets became important crops. These crops require late irrigation. More

water is needed in July than in June, and as much in August as in May. Before these crops, which have a high acreage value, need irrigation, most of the snow has melted and run to waste unless the water is stored in reservoirs. The Poudre River, in Colorado, will illustrate this. For the eight years from 1895 to 1902 the average flow for June was 1 877 cu. ft. per sec., for August, 322 cu. ft. per sec. There was too much water in the first month and too little in the last. The function of the reservoir is to regulate the escape of the water supply to meet the needs of the irrigator.

Within the last ten years more than 100 reservoirs have been built in the valleys of the Cache la Poudre and Big Thompson Rivers, in Colorado, to store the flood waters in the spring for use in the latter part of the summer. The greater number of these reservoirs are natural basins outside of the channels of the streams, experience having shown that these are both cheaper and safer than building dams in the streams' channels. Nearly all the embankments are earth. Fig. 3 shows the cross-sections of a number of the larger ones. The depth of water in the Poudre Reservoirs varies from 6 to 31 ft.; in those of the Big Thompson, from 12 to 40 ft. The height of the earthen dams above the water level depends somewhat upon the shape of the reservoir and the direction of the prevailing winds with respect to the dams. Where the dam is located so that the waves beat against it, the height of the dam has to be increased materially. In one instance the top of the dam is 12 ft. above high-water line. Usually, 6 ft. is regarded as a sufficient margin of safety. Twenty reservoirs in the Cache la Poudre have an average depth of 21 ft., an aggregate capacity of 99 000 acre-feet, and cost $654 530, or about $7 for each acre-foot of capacity. Colorado irrigators paid $7 per acre-foot for water last year. Eleven reservoirs on the Big Thompson have an average depth of 20 ft., a total capacity of 40 000 acre-feet, and were built at a cost of $8.30 for each acre-foot of storage capacity. The total cost of the 31 reservoirs on these two streams was $921 000. Statistics show that stored water increased the value of the agricultural products of the Poudre Valley in 1902 more than $1 000 000, and that the storage works of the Big Thompson Valley added $500 000 to the value of its products during the same year.

The laws governing the storage of water vary somewhat in the

different States, those of Colorado being the most explicit. These do not permit water to be taken from irrigators to fill reservoirs, but make the priorities for storage separate from and independent of those for irrigation directly. Only surplus and flood waters can be stored. Reservoirs may be built in the channels of streams, but the plans and construction are subject to the supervision of the State Engineer. Owners of reservoirs are liable for damage caused by leakage, overflow, or breaks in embankments.

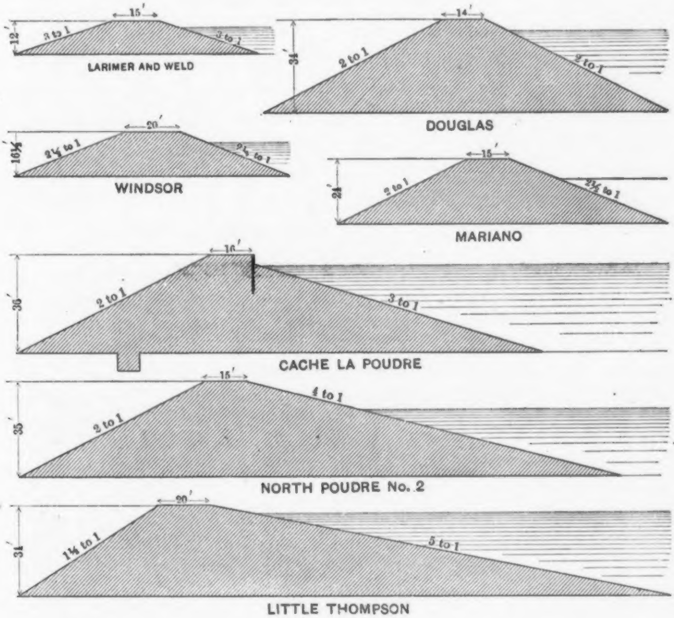

FIG. 3.

An extensive system of exchange in stored water has grown up in Colorado, and, to a less extent, in Utah. Parties having rights to store water exchange with those having rights in the natural stream, and, in this way, often prevent waste of water and save expenses of transportation. Owners of stored water are permitted to turn it into the channels of natural streams and have head-gates

regulated so as to insure the stored water being carried past ditches not entitled to use it.

Among the important storage basins now in use may be mentioned Lake McMillan, Pecos River, N. Mex., with a total area of 8 000 acres; the reservoir of the Wyoming Development Company, in Wyoming, with an area of 6 700 acres; the Twin Lakes Reservoir, in Colorado; and a number of smaller but costlier basins in California.

The National Reclamation Act.

The general need for storage to regulate the flow of rivers and make it possible to use the entire water supply, coupled with the desire for more rapid settlement of the arid public lands, led to the passage by Congress, in June, 1902, of an act setting aside the proceeds of the sales of public lands for the construction of canals and reservoirs by the Federal Government. President Roosevelt, in his message to Congress in December, 1901, made a strong argument in favor of this new national policy, saying, among other things:

"Great storage works are necessary to equalize the flow of streams and to save the flood waters. Their construction has been conclusively shown to be an undertaking too vast for private effort. Nor can it be best accomplished by the individual States acting alone. Far-reaching interstate problems are involved; and the resources of single States would often be inadequate. It is properly a National function, at least in some of its features. It is as right for the National Government to make the streams and rivers of the arid region useful by engineering works for water storage as to make useful the rivers and harbors of the humid region by engineering works of another kind. The storing of the floods in reservoirs at the headwaters of our rivers is but an enlargement of our present policy of river control, under which levees are built on the lower reaches of the same streams.

"The Government should construct and maintain these reservoirs as it does other public works. Where their purpose is to regulate the flow of streams, the water should be turned freely into the channels in the dry season to take the same course under the same laws as the natural flow."

The fund for canal construction which is accumulating under this act now amounts to about $27 000 000. Its expenditure is under the direction of the Secretary of the Interior, who has delegated the active direction of the work to the United States Geo-

logical Survey. A special Reclamation Service, having in its employ many of the best known irrigation engineers in the West, has been organized, construction on two projects has been begun, and the final plans for four or five others are now being prepared. Under this act the entire construction cost is to be repaid by the owners of the land benefited, the payments extending over a period of ten years. The fund will therefore be a revolving one, and, unless the law is modified, the money available must in time amount to an immense sum, as there are about 500 000 000 acres of public land yet undisposed of, and receipts from this source will soon be augmented by sales of water rights.

Under this act, the settlement of the water rights and the control of the distribution of water from streams rest with the several States. This makes it important that State water laws should be adequate and provide for a satisfactory adjustment of the respective spheres of Federal and State authority. Foreseeing the enlarged demand on streams which national aid would cause, the Secretary of Agriculture, in his report for 1901, made the suggestion that prior to the construction of any reservoirs under this act, each State be required to pass laws which would insure the definite and final establishment of titles to water and put an end to the granting of speculative rights, giving as a reason therefore that:

"If the States are to control the water supplies, there should be satisfactory assurance that whatever is made available by public funds shall benefit the actual users of water and not enrich the holders of speculative rights. In some States there is such assurance. These States are entitled to National aid, because it is known from present conditions that such aid would be clearly beneficial. But there are other arid States where the doctrine of riparian rights jeopardizes the success of every irrigation work now built, as well as any works which the Government might build. In other States rights have been established to many times the existing supply, yet there is nothing to prevent new claims being filed, new diversions made, and unending litigation over the conflicts thus created. For the Government to provide an additional supply on these streams before existing controversies are settled would simply aggravate and intensify the evils of the present situation. Whatever aid Congress extends should be conditioned on the enactment of proper irrigation codes by the States, and be made to promote the greater efficiency and success of such laws rather than interfere with their operation."

The need of such legislation by the States is now recognized by all familiar with Western conditions. The more Government works there are, the more clearly this necessity will be manifest. Government aid, therefore, promises to be a potent influence for the betterment of legal and social conditions.

Government construction makes it possible for engineers, in planning structures, to give more attention to durability than to first cost. This will have a beneficial influence upon the construction of new works by private enterprise as well as in the reconstruction of old ones.

Since 1900 the arid region has enjoyed great prosperity. There has been a great increase in Western settlement, and the values of both land and water have had rapid and continued advance. Land in the Yakima Valley, Washington, which could have been purchased five years ago for $15 an acre, now sells for $75 an acre. Land in the Turlock and Modesto Districts, in California, which sold for $20 an acre three years ago now brings $60 an acre. Water rights in Idaho, which in 1894 found no buyers at $10 an acre now have prompt sale at $25 an acre.

The Government projects exceed in magnitude and cost anything yet undertaken in this country. Each has a vital relation to the prosperity of the section where it is located. In every instance it will bring a new era of growth to a region which offers attractive conditions to settlers.

TRANSACTIONS

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IRRIGATION.

IRRIGATION AND HYDRAULIC MOTORS USED IN IRRIGATION IN FRANCE.

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Translated from the French by
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I. Irrigation.

Utility of Irrigation.—Although Continental France belongs by her climate to the temperate zone, and although extreme heat is as exceptional as extreme cold, it is seldom that during the course of any year there is an exact compensation or equilibrium between the alternate periods of dry heat and rain, which are equally necessary to vegetation.

Even in countries where the climate is ordinarily rainy, there are periods of drought when all agricultural economy is demoralized and when irrigation is the only means of saving the crops, in part at least. However, the absolute necessity of irrigation, in Northern and Central France, is only felt at irregular intervals.

This does not mean, however, that irrigation is not resorted to; it is, on the contrary, quite necessary to maintain the humidity

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required for germination in soils naturally too dry. Regular irrigation, every summer, for four or five months will alone give fertile fields, and the fertility of meadow-lands, which is a source of prosperity for certain regions, such as Normandy, for instance, is due to regular irrigation. When water is plentiful it is used sometimes to assist vegetation; it is needed by the plants and also gives them the mineral matter that it contains either in suspension or in solution. To that end, turbid or muddy water is preferable as it generally contains fertilizing matter. This irrigation, called "nutritive," requires a volume of water much greater than the ordinary irrigation called "quenching" or "refreshing."

In Southern France, and particularly in the southeastern region, the summers are very dry and very hot. Irrigation there is indispensable, and the quantity of water used during irrigation periods, that is from April 1st to October 1st, is much in excess of the rainfall during the same period. In this region there is really no cultivation to which irrigation is not useful. The meadows need it particularly, because those not regularly irrigated, are almost unproductive. Cereals, roots, industrial cultivations, all derive great benefit from irrigation during the summer. Finally, market and kitchen gardening is only possible when water is plentiful. The possibility of irrigating is then the essential condition to the existence of a number of remunerative gardens.

Quantity of Water Required.—The quantity of water necessary for irrigation does not depend entirely on the climate; it depends also, in a great measure, upon the nature of the soil and its degree of permeability. It varies also with several other circumstances, such as the intensity and distribution of annual rains, the hygrometric conditions of the atmosphere, the nature of the plants cultivated, etc., and cannot then be determined in a general way.

In warm climates, where irrigation is simply refreshing, a time-honored practice has helped to determine that the quantity of water necessary per hectare (2 acres) is equivalent to a constant flow of 1 liter per sec. during the 183 days of the period of irrigation.

In the central and northern parts of France, the quantity of water used for the spring and summer irrigation is variable, sometimes being as low as 0.25 liter per sec. per hectare, and again as high as 10 liters.

"Nutritive" irrigation requires a much greater quantity of water. In the Vosges, where this kind of irrigation has been used on a large scale from time immemorial, some fields receive, when water is plentiful, 200 liters per sec. per hectare.

Periodicity of Flooding.—Although it is customary to measure the quantity of water used in irrigating by the continuous flow of a certain number of liters per second per hectare, it is not in this way that the water is used, especially for refreshing irrigation in summer.

Even if the quantity of water is unlimited, the applications should be interrupted periodically for the good of vegetation. If, where the disposable quantity of water is limited to a continuous flow of 1 liter per sec. per hectare, the water were poured in a continuous stream it would only represent a sheet of water 0.36 mm. deep, and would be almost entirely absorbed by evaporation and would be absolutely insufficient even to moisten the ground.

The farmer must then arrange to apply water to each parcel of land, periodically, and for a few hours only, in a quantity equivalent to the volume that this parcel of land would receive if it were furnished to it during several days, at the rate of 1 liter per sec.

The meadows and lands devoted to market gardening which require a great deal of water, are treated once a week for about six months. For other plants, such as corn or cereals, a few sprinklings during the summer are sufficient; and shrubs, such as olive trees or vineyards, require only two or three waterings per year.

Practice has shown that for irrigation to be effectual, and in order to enable the farmer to lead the water on his land properly, the flow of the main source, during the operation, should equal 30 liters per sec. per hectare. This takes from 4 to 5 hours per hectare, and the period between two consecutive applications is from 6 to 7 days; and inasmuch as the irrigation season lasts about 6 months, it is then possible to make about 30 applications per year.

In some parts of France where irrigation is less indispensable, and where it is more specially used on meadows, the methods vary according to the nature of the subsoil. When the subsoil is pervious, the floods of rivers in the fall and winter render irrigation superfluous; in this case irrigation is used only in summer.

When, on the contrary, the subsoil of meadows is impervious, then

irrigation is used, not only in summer, but also in winter after frosts and until the time when grass begins to grow, and in the spring, to prevent the then bare ground from cracking under the influence of the first heat, and also in the autumn after great rains. Then turbid waters are used and enrich the ground by leaving upon it a thick muddy fertilizing layer.

Source of Water Used.—Water, other than rain-water, used in irrigation comes from springs, from ground-water or from streams.

The springs belong to the owner of the land in which they are located; with some rare exceptions, the landowner has a right to utilize them for the needs of his place.

He has also a right to sink wells to reach the ground-water. In order that the water so found can be utilized for irrigation, it has to be raised to the surface by machinery described farther on.

The conditions under which water from streams may be used vary according as these are navigable, or "floatable" (navigable for rafts and timber), or not.

Navigable or "floatable" streams, and navigable canals and their tributaries belong to the State. Some concessions for watering and irrigating may be granted by decree, but only subject to revocation, and upon payment of an annual rental.

On the contrary, the water of non-navigable and non-floatable streams, which include almost entirely the network of rivers in France, does not belong to any one;* the owners of land bordering on those streams have only the right of using the water. They can gratuitously use the water for irrigating their land, provided they restore to the stream all water which has not been used or absorbed, at the lowest limit of their property. They even have the right of using the water in irrigating parcels not bordering on the stream and belonging to them. The law of April 29th, 1845, gives them the right to dig irrigating ditches through lands belonging to other parties upon payment of a preliminary and fair indemnity.

Private Irrigation.—Notwithstanding the right of using the water granted to landowners along streams, the supervision of all non-navigable and non-floatable streams belongs to the State. As a consequence, no water can be taken for irrigating purposes, even if

* While the total length of the network of non-navigable and non-floatable streams exceeds 260 000 km., the navigable or floatable streams have only a length of 11 757 km., and the canals a length of 4 930 km., or a total of 16 687 km.

it is done only by a simple cutting of the shore of the stream, without a special permit signed by the Prefect of the Department. In general this permit does not limit the quantity of water which the landowner may divert.

If this diversion, by its importance, is detrimental to other parties by robbing them of the water which they require, or if the general interest is jeopardized, the Administration has the right to interfere, either by fixing the minimum volume of water which must at all times flow in the river, by dividing the water among the different people using it, *i. e.*, manufacturers and farmers, or by determining the volume of water to be used for irrigating purposes. Law-suits, among individuals, which result from diversion of water, come under the jurisdiction of the civil courts.

When, in order to make irrigation practicable, it is necessary to raise the level of the water at the point where the diversion must be made, the owner, upon application, may be authorized to build a dam across the stream. If he owns land along one shore only, the law of July 11th, 1847, gives him the right to request that facilities be given for abutment on the other shore. The dam is regulated by prefectoral ordinance determining the head of water; it does not fix the dimensions of the intake gates but gives rules about their closing after the irrigation period is over.

Owners of land not bordering upon non-navigable and non-floatable streams are not without some rights upon these streams. They may divert water for collective irrigation. The laws of June 21st, 1865, and December 22d, 1888, on syndicates and associations enable them to organize themselves into authorized irrigating associations. If the enterprise is recognized as being a public utility or benefit, the association is authorized to divert from the stream a certain volume of water fixed by the permit. As a basis for determining this volume, it is only necessary to admit that the area of ground really irrigated will amount to one-third of the land included within the perimeter of the irrigation ditch and that the allowance will be 1 liter per sec. per hectare.

The same authority can be granted by law or by decree, to a department, to a town, or to a grantee company. Such a law is necessary for important enterprises, in other cases a decree is sufficient.

When the concession is granted to a department, town, or syndicate, it is generally perpetual; when it is granted to a grantee company, it is usually limited to a maximum of 99 years, and at the expiration of the concession or franchise the canal reverts to the State, department, town or syndicate, as the case may be.

Subsidies.—The cost of building large irrigating canals is very great; that is why the State grants subsidies, which are not to be reimbursed, to promoters of such enterprises, but always leaves the greater part of the expense to the consumers.

This help from the State takes different forms. Between 1874 and 1882, a system was tried whereby the State guaranteed to all great irrigation canals a minimum earning equal to the amount of expense to be borne by the company; this was done with a view to encourage the construction of these works and at the same time to reduce the importance of the subsidies and grants from the State. But this arrangement had to be abandoned owing to the extreme difficulty found in selling the water of these, usually very expensive canals, to farmers who cannot educate themselves to recognize water as a merchandise which may be sold to them by a corporation. On the contrary, on canals built by the consumers themselves, the dues for water used are generally collected without any difficulty.

Another kind of subsidy from the State has been adopted more recently, to assist the construction of the irrigating canal of Manosque (Basses-Alpes), now finished. The work, which cost 4 500 000 francs, was done entirely by, and at the expense of, the State. Upon completion, the canal was turned over to a syndicate, composed of consumers, which was charged with the operation, maintenance, and the collection of dues or rentals levied upon those using the water. For 50 years the State will levy 70% of the net earnings from these dues or taxes, to reimburse itself.

The desire of the French Government is to allow the consumers, organized in authorized associations, or syndicates, to build and operate irrigating canals at their own risks.

The construction is made easier by a subsidy given once for all and amounting to one-third of the estimated cost of the work.

The total amount of subsidies granted for the construction of irrigating canals built during the last 25 years is more than 37 000 000 francs. Fourteen large canals have received a subsidy

of more than 1 000 000 francs; the largest subsidy, granted to the Bourne Canal, near Valence (Drôme), has reached 4 850 000 francs.

Methods of Construction of Irrigating Canals.—When the State takes charge of the construction of an irrigating canal, the work is designed and constructed by the engineers of the roads and bridges, in charge of the Hydraulic Department.

In other cases, grantees may have the advice and collaboration of the State Engineers whenever they ask for it. As a matter of fact, the greater number of the irrigating canals have been built under these conditions. When the work is done at the risk of the consumers, the State supervises the work only in so far as it is necessary, not only to insure proper construction, but also to see that the grants or subsidies are paid to the grantees as the work progresses, by instalments amounting to one-third of the cost, verified and certified by the accounting department.

The grantees must raise the capital necessary not only to cover the cost of construction left to their care, but also to raise a sufficient fund for the proper prosecution of the work.

In order to meet these requirements, the companies can issue bonds, or ask for loans by mortgaging the State grant as well as the future resources of the enterprise. As to the syndicates, the laws of June 21st, 1865, and December 22d, 1888, which regulate them, give them also the right to borrow capital; they give to the lenders full guaranties of reimbursement, the Prefect having power, if necessary, to appropriate certain sums to the payment of debts, and to recover the amount so used in the same way as Government assessed taxes are levied.

Operation of Irrigating Canals: Financial Operation.—The grantees of irrigating canals are authorized to levy annual dues upon the people using the water, not only for irrigating purposes, but also for domestic uses, for pleasure, or for hydraulic motive power.

The tax for irrigating is usually fixed upon the basis of a continuous flow of 1 liter per sec. per hectare.

This price varies from 35 to 70 francs per year. Except when the State has a right to retain a certain percentage of the taxes to reimburse itself for works constructed or for advances made, the

entire proceeds belong to the grantees as a remuneration for their work, maintenance and operating expenses.

In enterprises of less importance, granted to associations of consumers, it happens at times that these parties bear all the expense without borrowing any funds. In this case, the cost of construction and maintenance is divided among the consumers who are assessed to the *pro rata* of the areas of their irrigated lands.

Operation of Irrigating Canals: Technical Operation.—As has been said before, in regions where water is indispensable to vegetation, the ground is irrigated once a week for 4 or 5 hours per hectare.

The great irrigating canals are located on the slope of hills and command areas of land, sometimes very large, on which are distributed the parcels to be irrigated; in order to water all these plots, it is necessary to establish a complete network of small canals or ditches diverted from the main canal. The perimeter, so controlled, is subdivided into zones separated from one another by ridges, each supplied with water by a secondary canal receiving some of the water of the main canal, and occupying the summit of one of the ridges. The secondary branches bring the water to the several parcels through ditches called collective or private according as they supply several properties or only one. The system of canals and ditches of all classes is very similar to the system of natural waterways, brooks, creeks, rivers. But the water flows in a reverse or'er from the larger to the smaller so that the two systems may be compared to the arterial and veinous systems of the human body. The network of the second- and third-class canals often attains a great development. In the case of the Canal des Alpines, diverted from the Durance, and which comprises a series of separate branches, the principal canal has a length of 118 km., while the network of small ditches amounts to 390 km., irrigating an area of 3 800 hectares.

During the whole period of irrigation, the main and secondary canals are kept supplied with water; on the contrary, the canals of the third-class, or irrigating ditches, are filled only periodically and for a length of time varying with the area of the lands which they must irrigate, because the volume of water furnished to consumers is constant and equal to 30 liters per sec., and is independent of the area to be irrigated. This irrigation lasts 5 hours per hectare. On the main canals the gates are operated by watchmen or guards.

At the beginning of each season, a schedule is drawn up and so arranged that all interested parties receive, during each period, the water to which they are entitled, independent of the time necessary for the watchmen to operate the gates. The land being generally very much subdivided, the number of landowners is, of course, great, and it is necessary to irrigate day and night. In order that the same people may not get their quota always at night, there is a fractional period of six and a half days, for instance, between two successive irrigations. When there are tracts of land large enough to warrant a very long period of irrigation, they are served preferably toward evening; all that has to be done is to open the flood-gate and to close it the next morning. Usually there is no interruption in the use of the water, and as soon as one landowner is through irrigating, another begins. The consumers are notified in advance of the day and hour when the water will be turned on and off their lands at each irrigation; they may thus take the necessary steps to utilize the water in a proper way. If they allow their turn to pass, they must wait till the next week to get any water, and this is a very serious matter to them because the lack of even one irrigation is sometimes enough to ruin or spoil a crop.

For the same reason, it is necessary to have the schedule carefully drawn up in order to avoid any mistake on the part of the guards. In order to insure perfect regularity in the working of the schedule and to correct any mistake or fault which may be found in it, there is a general rehearsal of the operations before the opening of the irrigation season.

In the south, the canals are often used, outside of the irrigation season, either to submerge the vineyards, in order to cure the vines of phylloxera by keeping them under water during the winter from 40 to 60 days, or to remove the salt from certain clay soils, previously saturated with salt water, which have retained the salts which ascend to the surface under the combined influence of capillarity and evaporation. This operation consists in dissolving the salt contained in the soil and on the surface by abundant irrigation renewed every year.

When it is necessary to make repairs, the canal is drained, usually toward the end of winter, when these submersions are over, and before the irrigation season has begun.

Results of Irrigation.—In the case of collective irrigation, the

water is furnished to the consumers at the highest point of the property to be irrigated, and every one has to utilize the water as well as he can.

In order that the irrigation be entirely beneficial, it must, according to the theoretical formula, reach everywhere and remain nowhere. To obtain this result, the owner must prepare and adapt the land to the kind of irrigation most appropriate to the nature of the soil, to the slope of the ground, to the kind of culture, etc. He must provide also for the drainage of the water not used or absorbed by the ground or the plants, by a system of drains or channels, in order to avoid stagnation. Except in the case of certain irrigation done on a large scale with impure water containing fertilizing matter, the irrigating operations do not exempt the consumers from the use of fertilizers without which the ground would rapidly become exhausted. It is evident that besides the cost of irrigation itself, the landowner is put to rather heavy expense in order to prepare his ground and lay out the interior of his land; this may be estimated at from 500 to 800 francs per hectare.

Nevertheless, it has been estimated that irrigation in France brings an increase in net earnings of at least 200 francs per hectare, after deducting all incidental expenses. The surplus value of the real estate after irrigation can then be estimated at 4 000 francs per hectare at least, and this reaches a still higher figure in land of poor quality.

It often happens that small landowners have not the necessary means nor the agricultural knowledge to prepare their land suitably for irrigation. They can borrow funds at 2 or 3% interest from the "Credit Mutuel Agricole" (Mutual Agricultural Loan Association) organized on new lines by the law of March 31st, 1899. Moreover, there is a Bureau of Agricultural Improvements at the Department of Agriculture, which gives free advice and consultation to farmers and landowners who are desirous of preparing their land properly for irrigation.

As to the private enterprises of great irrigation canals, if they have, as in several cases, shown remarkable results, they have in others ended in failure, especially when the concessions have been granted to companies having a capital to reimburse. They have no revenue, other than that derived from the sale of water, to meet

the expense of first cost and maintenance, which varies according to the conditions under which the canal has been built and which is often very high. In order that the canal may command a large area of ground, the water of the feeding river must be diverted at a point much higher than the beginning of the zone to be irrigated, and brought down to where it must be utilized by a canal with a very easy slope called "dead head." Sometimes the "dead head" which does not furnish irrigation water to any parcel of land, is very long, and its construction, owing to the configuration of the ground, the erection of several incidental works (culverts, trestles, bridges, etc.), and to operations making the canals water-tight, may have cost a great deal.*

The capital, sometimes very great, used to build the "dead head" as well as to execute the final construction, remains idle. On the other hand, the annual maintenance of the main canal and its tributaries greatly increases the expenses of the company, which, obliged to furnish water at a very low rate in order to find a market for it, can only make a very small profit. It must be noted that the area irrigated by the water of the main irrigating canals increases but very slowly. In the case of the Canal of St. Martory, diverted from the Garonne, and which commands a rich plain stretching almost to the gates of Toulouse, while the area that could be irrigated is equal to 10 700 hectares, the area really irrigated was only 2 643 hectares in 1894 and 2 976 hectares in 1904, that is only an average increase of 33 hectares per year. The construction of new canals of that importance seems to have been abandoned. As has been said, it is preferable to grant the canals found to be necessary, to syndicates, and also to divide the enterprises by increasing their number.

The system, which consisted in connecting the network of distributing arteries to the feed water of the river by a "dead head" of great length, has been also superseded and condemned, not only because of the great cost of construction of these "dead heads," but also because the evaporation, so important in the south, reduces very materially the volume of water brought to its destination, and

*An idea may be had of the importance of the work done in connection with making the works water-tight when it is stated that in the Marseilles Canal the losses recorded on the main canal, the length of which in the open is 67 km., was equal at first to one-fifth of the volume diverted from the Durance. Special works to make it water-tight, costing more than two millions, have materially reduced these losses.

because it is impossible to prevent this loss. In certain proposed enterprises the utilization of hydro-electric energy has been considered. One of the projects contemplates irrigating an area of 3 800 hectares. At the point where, formerly, the diverting dam was located, a spillway creating a fall of 70 m. and capable of furnishing an energy equivalent to 11 200 h. p., of which the irrigation will absorb 3 000 h. p. at the most, is to be erected. The electrical energy will be transmitted overhead along the river and will operate 6 pumping stations. In each of these stations, centrifugal pumps will raise and force the water to the head of an equal number of main ditches which will be so located as to distribute the water over the whole area to be irrigated. The remainder of the disposable energy will be used in several other ways, lighting of towns, motive power, etc.

With so many useful applications it is to be hoped that there will be a fair return on the capital invested.

In spite of what has been done already in that direction during the second half of the nineteenth century, there is yet much to be done in France in order to improve irrigation to a degree justified by the extent of the cultivated lands.

A census taken in 1902 has shown that the area of the lands regularly irrigated was 1 453 000 hectares. There existed then 3 877 irrigating associations and 37 grantee companies of main irrigating canals. There are 57 canals, the flow of which is more than 1 000 liters per sec. The most important ones are in the Department of Bouches-du-Rhone: the Craponne Canal, with a flow of 13 cu. m.; the Canal des Alpines, with 12 and 10 cu. m., and the Marseilles Canal, with a flow of 9 cu. m., all three diverted from the Durance.

II. Hydraulic Motors Used in Irrigation Works.

Private Irrigation: Dams.—It has been said that the owners of land bordering along waterways have the right to use the water to irrigate their land. It is seldom that irrigation can be done with only a channel cut through the shore; it is more often necessary to raise the level of the stream by a dam. The owner whose land is located on one shore only, has the right to build a dam as well as the man whose land is on each side of the stream. As before stated,

the law of July 11th, 1847, gives him the right to abut the dam on the opposite shore; the owner of the other shore is entitled to use the dam and the water so raised, provided he pays half the cost of construction and maintenance. The irrigation dams are very simple and usually consist of one or several timber gates moving vertically between guides; these gates are lowered during the irrigation period, at all other times the owners are obliged to raise them above the highest stage of the water so as not to interfere with the flow of the stream.

The height of the level so raised by such a dam is always small, and the alluvial lands along the streams alone are capable of being irrigated by this method.

It is generally necessary to raise the water by mechanical means and to force it to a certain distance. Sometimes the fall is used to run some lifting machinery such as hydraulic rams. Electricity also is being used now to raise water.

For instance, if a landowner, having built a dam, wants to utilize the energy of the fall to irrigate land bordering on the river but higher up and rising from the river shore, the irrigation water is raised by an electric pump. The motive power generated by the dam being much more than is necessary to irrigate, the remainder of the hydro-electric energy is used to operate several agricultural machines and also for lighting.

There are on the streams in France a great number of dams of average importance which in the past were used to furnish motive power to small factories, particularly to flour mills which are now closed because of the competition of newer and larger plants. The French Government desired to see these dams in working order once more and to see this lost energy used. It has decided that subsidies should be given to owners who would be willing to try and transform the energy of these falls into electrical energy to be used in agricultural operations. The enterprise which has been spoken of before, has received a very important grant or subsidy. Moreover, the plans and estimates have been drawn up and calculated by the State Engineers and the work constructed under their direction. This example of utilization of hydro-electric motive power seems to be in a good way to be followed by several other owners.

Various Motors.—When there is no hydraulic power and the lands to irrigate are far from any stream, windmills are used to raise the water from wells and store it in reservoirs. The windmills used nowadays are all improved engines known under the name of "æolians," "aeromotors," etc. They are of several types, varying only in details of construction. They consist substantially of a metal frame or tower upon which is set a wheel geared to and running the piston rod of the pump. The wheels revolve automatically around the axis of the tower according as the wind is light or strong, in order to transmit the power at a uniform speed, independent of the velocity of the wind.

In some rare instances, the pumps are operated by horses, or even by hand in a few very small plants. In some other cases where the volume of water to be pumped is very large, steam self-propelling engines are used as well as gas engines, gasoline motors and alcohol motors. Generally these motors are not only used to raise water, but also to perform other duties on the farms, either by means of a transmission shaft or by actuating series of electro-motors.

Lifting Machinery.—The motors just described are used to run lifting machinery. There are two principal types of machines, hydraulic rams and pumps. The ram is generally worked automatically by a waterfall of a comparatively small height, but its capacity, which decreases rapidly with the ratio of the height of the fall to the height of the lift, is not generally greater than 50 per cent. Some improvements made in that type of machinery and apparatus known as the automatic pump and the hydraulic lift, permit using the motive power alternately on the two faces of a horizontal piston, or else forcing the water in two tanks connected to a common pipe through which the water ascends. This apparatus is really an automatic lift and force pump doing double duty and, therefore, of a greater capacity than the ram.

Pumps used in irrigation are actuated either by hand or mechanically. The former are only used in small places and are either winding pumps, rotary pumps or pumps of the usual balance-beam and piston type.

The mechanically operated pumps are of the three principal types:

1.—Piston pumps capable of good work, of great lifting and

forcing power, but usually heavy, cumbersome and slow, and fitted with valves which wear out quickly;

2.—Rotary pumps, which have good capacity and the advantage of being light, without valves, and taking up little room, but which wear out quickly and can run only at a very moderate speed;

3.—Centrifugal pumps, which are the most recent ones. They are specially well adapted to raising large volumes of water to a small height. Their speed is such that they may be run directly by electric motors, and their output is very great as long as the lift does not go beyond certain limits.

There are also pumps connected in series or batteries, and double-acting or quadruple-acting rotary pumps, as well as several other engines derived from the three principal types and combined to suit the various requirements either of the height of lift or of the height to which a certain volume of water must be raised.

Collective Irrigation.

Water Supply.—As has been seen before, the canals bringing the water used for collective irrigation are all located in such a way that the main branch commands the territory to be irrigated and each party receives the water at the highest point of his land. When it is possible, the water level is raised at the beginning of the canal by a permanent dam built across the feeder. All the large canals, except those diverted from a navigable stream, such as the Rhone, or from a river like the Durance, and which cannot be dammed because of their great width and torrential conditions, require a masonry diverting dam.

Some of these head-works are quite important, particularly the dam of the Bourne Canal which measures 17.5 m. in height and is 72 m. in length. These dams have spillways to discharge the surplus water from floods, and gates to regulate the volume and flow of water.

Canals without dams have gates controlling a stretch of canal, the cross-section and length of which are known, so that the volume and flow of water may be ascertained at all times by reading a gauge.

Sometimes the water feeding the irrigation canals must be raised mechanically. Such is the case for several canals irrigating

Camargue Island in the delta of the Rhone. In this region irrigation is indispensable, for while the annual mean height of rainfall is but 0.60 m., it has been calculated that the annual evaporation of the water of the Valcarès Lagoon, at the southern end of the delta, under the influence of the sun and wind, amounts to a body of water having the same area as the lagoon and a depth of 2.50 m. The level of the island being lower than the flood level of the Rhone, levees were built around it as a protection against floods, and the canals supplying it with water are fed by centrifugal pumps and metal siphons passing over the levee. The Sambuc Canal, which is to irrigate an area of 1 350 hectares, has just been finished under these conditions by a syndicate. The flow of the canal is 1 000 liters per sec. The water is raised mechanically to a height of 4 m. by a pumping plant located back of the levee and composed of two compound engines, each running a centrifugal pump of 500 liters capacity.

Incidental Constructions.—Irrigation canals, which with their branches often reach a length of several thousand kilometers and traverse rough and rolling lands, often require the construction of many adjuncts, such as bridges, aqueducts, siphons, tunnels, etc. It may be mentioned here that the famous Roquefavour Aqueduct, with its length of 380 m. and its 80 triple superimposed arches, built by de Montricher, stands on a par with the gigantic Roman bridge-aqueducts (the Gard Bridge), the ruins of which may be seen in parts of Southern France. This aqueduct, supplied by the Durance, is the most important of the works on the Marseilles Canal, and serves both as a supply for the city and to irrigate the land through which it flows. Another large irrigation canal which has made necessary the establishment of remarkable constructive works is the Verdon Canal, supplied by the river of the same name, a branch of the Durance. It irrigates the lands of the vast plain of Aix-en-Provence, which is devoted principally to the culture of olive trees; one of its main branches has a length of 80 km., of which 20 km. are in tunnel, and called for the construction of three great bridge-aqueducts and six large steel-plate siphons each made up of two tubes measuring 1.75 m. in diameter.

The Manosque Canal, recently finished, has seven large cast-iron siphons aggregating a total length of 2 700 m. and each made

up of two rows of pipes with diameters varying from 0.80 to 1.10 m.

In earthen canals, although earthen embankments are not used more than is absolutely necessary, in order to stop the losses due to leaks and infiltrations, the banks are revetted. These revetments are usually made of stone masonry or concrete.

However, in the case of the Sambuc Canal, where the nature of the ground required its construction in an earthen embankment, and as the losses due to infiltrations were supposed to be very great, owing to the fact that they would have caused the raising of the salt to the surface in all the surrounding lands, it was decided to build a steel, reinforced cement flume of semi-circular cross-section and resting on an earthen embankment. The highways were crossed by means of siphons made up of steel and cement pipes; the flume was carried on trestles over ditches and canals. The results have been very good, and it is probable that, in the future, steel reinforced concrete alone will be used in all revetments.

Distribution of Water.—The volume of water which is the legal quota of each canal, is fed to the main canal and gauged by the head-work or intake. It is then distributed among the several branches and arteries leading the water to the summit of each parcel to be irrigated. At the point where each irrigating ditch leaves a ditch or channel of greater importance, is located a special weir or head-work the duty of which is to measure and gauge the water so that it may be distributed as required between the two channels.

At the head of each branch diverted from the main canal, there is sometimes a gate which can be operated only by the watchman whose duty is to keep the channel filled; a graduated gauge gives, by reading, the height of the water and therefore the flow and the quantity. At times a reinforced cement pipe leads into a rectangular tank closed at the opposite end by a sill above which the water can spill in a thin sheet easily measured.

As to the irrigation or distribution ditches, their supply is constant. The length of time during which they are fed alone varies. This supply is controlled by head gates regulating the flow. When the same intake must supply several ditches, the distribution between these ditches is done by square tanks perforated by openings of the same shape and dimensions at equal distances from the intake.

All these regulating devices are operated by the canal watchmen; only the flood gate located at the head of each property is operated by the consumer. As the water of the same irrigating ditch is always supplied to the consumers beginning at the point farthest from the main canal, all that the consumer has to do is to open his gate at the appointed time. Once his flooding done, the next consumer opens his gate, and the water flows in his land and stops flowing in the preceding consumer's.

Thanks to acquired habit and regulations, this distribution of water goes on uninterruptedly and regularly, every consumer being anxious to do his share toward preventing mistakes and delays.

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IRRIGATION.

IRRIGATION IN THE HAWAIIAN ISLANDS.

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The development of irrigation projects in the Hawaiian Islands has been prosecuted with the greatest vigor by private corporations owning sugar estates, during the last ten years. No aid for this work has been received from either the local Territorial Government of Hawaii or the National Government at Washington. What was formerly arid and unproductive soil, covered by wild brush and pasturing a few cattle, has been converted into productive sugar-cane land, by the application of water, at a heavy expenditure of money and enterprise.

Rainfall.

The rainfall of the Hawaiian Islands is very local and peculiar in its distribution. The trade-winds blow off the ocean from the northeast, and on this slope a rainfall of from 60 to 200 in. per annum is quite common, the intensity varying with the altitude and local configurations, while on the lee sides the rain is often as light as from 10 to 15 in. The islands as a rule are quite

rugged, varying in altitude at their central and highest points from 3 000 to 10 000 ft. The windward sides are covered with a dense brush which remains green throughout the year. On the northeast slope of Maui the maximum precipitation occurs at an altitude of 1 500 ft., being often as much as 400 in. per annum at Nahiku, while at sea level and higher up the mountains it is only one-third of this quantity.

Uses of Water.

Water is used for irrigating the sugar cane, the annual crop of sugar each year amounting to 400 000 tons, which averages $70 a ton, or $28 000 000. One-half of this is due to the development of irrigated plantations during the last twenty years. The remaining 200 000 tons are raised on rainfall plantations which are very uncertain in their output, owing to the precarious rain conditions prevailing.

Ancient Water Rights.

The remains of old houses and fields bear convincing testimony that the population of Hawaii was very dense in prehistoric times. Nearly all the streams were led out by ditches called "auwais," and the water was used for growing "taro," the national food, and other vegetables. The ditches were excavated in surface earth and maintained by the joint users, each of whom had to devote so many days each month toward repair. The water was also distributed among its users by set rules and at stated times, each district with its branch ditch getting so many hours' flow of the stream. The land thus cultivated was always in the vicinity of the stream, as no long ancient conduits were built, and was styled "taro" land in contrast to "kula" or dry land which carried no water rights.

The native Hawaiians have protected, with the greatest zeal, their water rights to taro land, which the gradual growth and expansion of sugar-plantation interests have tended to absorb.

Modern Irrigation.

The present water supply of the islands is derived from two sources:

1.—By pumping ground-water or artesian waters from wells and sumps, excavated near the seashore. The pumps are driven either with coal or oil as fuel, or by electricity generated from water-power.

2.—By gravity from the natural flowing streams, the impounding of the flood waters of these streams, and by the interception of ground-water by tunneling.

One of the most striking facts which the Continental engineer has to experience is the extraordinary productiveness of some of the island water-sheds, and this destroys at once many preconceived theories as to what run-offs should be. The Waihee watershed on Maui with an area of about 4 sq. miles, yields a daily minimum flow of 17 000 000 gal., while the Olokele water-shed on Kauai Island, with an area of about 8 sq. miles, yields a minimum flow of 40 000 000 gal., and a mean flow of 70 000 000 gal. in 24 hours. Each of these water-sheds is peculiarly and favorably situated for precipitation, with steep brush-covered slopes, and with almost daily rainfalls.

Nearly all the Hawaiian streams respond very quickly to rainfall, rising and falling quite rapidly; while those with a good dense brush-covered water-shed hold the volume in the streams almost constantly above a certain minimum.

The artesian supply of the Island of Oahu is the most peculiar and the most generous found in any country of such a limited area, the island being only about 12 miles wide, north and south, by 35 miles long, with mountain ranges near its north coast 3 000 ft. high. It yields daily from wells and sumps 250 000 000 to 300 000 000 gal. without any apparent diminution of the supply, the source of which is in porous strata found at a depth of from 400 to 800 ft. below the sea level. The static level of the water in the wells penetrating this formation varies from an elevation of 40 ft. above the sea at Honolulu to 22 ft. at Ewa Plantation, 16 miles westward. Excessive pumping or prolonged droughts vary this level somewhat, but it is always restored quickly on the cessation of the affecting conditions.

The islands are all of porous stratified lava formed in layers by successive emissions from the ancient central cones which now form the summits of the islands. The water supply in the artesian

strata near the sea is sustained by mountain precipitation, and the intimate connection between the mountains and the wells is proven by the sudden discoloration of the water in the latter some hours after heavy rainfalls in the mountains.

The artesian condition of the Oahu strata is caused by a tight coral and clay cushion which rests on the foreshore and prevents the water from escaping to the sea. In none of the other islands, owing to the absence of this necessary formation, is artesian water found, the pumps being fed from sumps excavated 5 to 8 ft. below sea level, in all of which the water level fluctuates from 1 to 2 ft., corresponding with the tidal changes, which vary in this tropical region from 2 to 4 ft. between low and high waters. The depth to which it is safe to lower the static water level in Oahu wells by pumping has been tested on each plantation. The rapid increase in salt per gallon by excessive pumping, and the consequent lowering of the water level, forbids extreme practice in this respect. The Oahu artesian waters carry from 8 to 20 gr. of salt per gal. in normal condition, while water with salt as great as 60 gr. per gal. will irrigate sugar cane successfully. The pumping stations are usually fed by a series of 12-in. wells, spaced 50 ft. apart and connected by a larger pipe, with the suction ends of the pumps placed at as low a level as practicable. One million gallons have been pumped out of each well thus spaced, and 10 wells have been found sufficient for a 10 000 000-gal. pumping engine, which is the general size of the unit.

The water is usually pumped through a 24 or 30-in. discharge pipe, varying with the size of the pump and the head. Most of the water is delivered below an elevation of 300 ft.; though, in a few instances, lifts as high as 450 ft. have been pumped against. The uncertain and fluctuating prices of sugar, the cost of fuel, and other expenses practically preclude all profitable pumping above 400 ft. The work of pumping 10 000 000 gal. daily to 300 ft. elevation with the ordinary pumps in service will consume 15 tons of coal, which at $8 per ton, would mean $120 per day for fuel expense alone. The cost of labor, lubricants, depreciation, etc., have to be added to get the total cost. Owing to the extreme fertility of the soil, as many as 8 and 12 tons of sugar per acre are raised, which yields a return of about 10 to 12% on the invest-

ment. Five plantations on the Island of Oahu, namely Kahuku, Waialua, Waianae, Ewa, Oahu and Honolulu, have a pump capacity of 287 000 000 gal. daily, with a water horse-power of 11 847, and draw water from 195 wells. Waianae furnishes the novel feature of using the fall in some gravity water found in its high levels (500 to 1 400 ft.) to develop power, after which the water is again used for irrigating the lands lower down, while the power is transmitted to electrically driven pumps near sea level to lift groundwater from wells to the 150-ft. level.

Maui comes next, with a pump capacity of 140 000 000 gal. daily, or 6 945 h. p., the water being drawn from sumps. Kauai has 55 000 000 gal. daily pump capacity with 2 033 h. p., drawing principally from sumps; while Hawaii, which is the largest of the islands, has only one pump of 7 000 000 gal. capacity, or 412 h. p., pumping from a shaft and sump.

The steep slopes, porous soil and high elevations of the plantations have prohibited irrigation on the Island of Hawaii, which, geologically, is the most recently formed of all the islands. No flowing surface stream exists for a distance of 200 miles on the coast, from Kohala southerly around to Hilo. The soil is of such a porous nature that it passes the rainfall through like cinders, and allows no surface accumulations of water. It has the Volcanoes Mauna Loa and Kilauea intermittently active, which emit two distinct varieties of lava; "Pahoehoe," which is heavy and compact, having sometimes a smooth, glassy and undulating surface; and "A. A.," which is of much less specific gravity than the former, often floating on its surface during flows and breaking up into all kinds of disintegrating masses on cooling.

Experience with the direct-acting, slow-moving pump of the Worthington type has not been encouraging. All new pumps now installed are of the high-speed, fly-wheel type, which consume much less coal; and, where all fuel has to be imported expensively, the greatest economy in this direction has to be exercised. The pumps are nearly all installed in concrete-lined pits, 36 to 50 ft. square, excavated to the water level, while the boiler plants are on the ground surface above. In three instances, at Oahu, Kihei and Kohala, the experiment of sinking shafts from the ground surface, 200 to 300 ft. down to the water level, and excavating

pump compartments at this level has been tried. The difficulties of ventilation and the expense of the shaft and chamber have more than balanced, in each instance, the saving of cost of placing delivery pipe on the surface, and of the friction loss in such pumps, which were the principal inducements for installing this system. The ground-water in such a shaft, two miles from the sea, has also been found as brackish as water found in wells, 100 yd. from the beach.

Outside of Oahu all pumping has to be prosecuted very cautiously, as too great a lowering of the sump level will increase the quantity of salt in the water, running it up to 100 or 200 gr. per gal., which renders it unfit for irrigation purposes, as it incrusts the soil with salt and damages the cane plants. Owing to the great porosity of the rock formations and the heavier specific gravity of the sea water, the tendency of the latter is to force itself inland where any vacuum is created by excessive pumping and consequent lowering of ground-water.

Gravity Supplies.

All available streams are now tapped by ditches on Maui and Kauai. The first was built on the windward side of Maui in 1878 by Mr. H. P. Baldwin and Mr. S. T. Alexander. The next was built in the same section by Mr. Spreckels in 1879-80, under the supervision of Mr. H. Schussler, of San Francisco, as engineer. It is about 30 miles long, of 50 000 000 gal. daily capacity, delivers the water at an elevation of 250 ft., and is known as the "Haiku ditch." This ditch was intercepted by a new work, called the "Lowry ditch," in 1900, which delivers the water at an elevation of 450 ft. The writer has just finished a new aqueduct, known as the "Koolah ditch," which taps all the Nahiku rain belt at an elevation of 1 250 ft., and discharges into the older and lower ditches. It is 10 miles long, 7½ miles being in tunnel and 2½ in open ditch and flume. The tunnels are all in solid rock. They are 8 ft. wide and 7 ft. high, with a daily capacity of 85 000 000 gal. Owing to the extreme porosity of the lava rock, 4½ miles of concrete lining, 6 in. thick, is used in the tunnels to prevent seepage. The work was all done by Japanese with hand-drills; ore cars were used in moving the excavated materials, and its finished cost has been

about $7 per lin. ft. The Japanese make excellent miners and rock men, and, owing to their small size, it was practicable to work four in a face, and by working three 8-hr. shifts, the whole work has been completed in eighteen months from the date of commencement, April, 1903. There are 38 tunnels, each averaging 1 000 ft. long, the shortest being 300 ft. and the longest 2 710 ft. The country was so steep and precipitous that little ditching could be used, and it was necessary to make 4½ miles of wagon road and 18 miles of stone-paved pack trails to facilitate, during construction, the transportation of supplies. About 4 000 bbl. of cement and 100 000 lb. of giant powder were used. In all, ten mountain streams are intercepted, which are admitted into the main aqueduct through screens of grizzly bars, spaced ⅝ in. apart.

The Honokahau ditch—with 30 000 000 gal. daily capacity—has just been finished on West Maui. It is 13½ miles long, on a grade of 5 ft. per mile, and has 2 000 ft. of 36-in. siphon pipes and 3½ miles of tunneling, and has cost $185 000. It delivers water at an elevation of 700 ft.

All the streams on the Island of Maui, including the Waihee stream, are now tapped by ditches, previously referred to, at Wailuku.

The "Hanapepe ditch," Makaweli, Kauai, was built by Mr. Baldwin in 1890, to tap the stream of that name. It has 7 040 ft. of 40-in. riveted steel siphon pipe, 1 013 ft. of tunnels, 14 618 ft. of flume, 5 ft. wide by 40 in. deep, and 10 miles of ditching on a general grade of 6 ft. per mile, and carries 35 000 000 gal. daily. The use of wooden flumes in tropical countries is not advisable, as repairs have to be made frequently, owing to the rapid decay of the wood. This ditch delivers water on the plantation at 450 ft. elevation; and a new one, just built and completed under the writer's supervision, known as the "Olokele ditch," delivers water at an altitude of 1 075 ft., and has a daily capacity of more than 60 000 000 gal. It involves 8 miles of 7 by 7-ft. tunnels, 5 miles of ditching, and it has cost completed about $360 000. At one point a drop of 228 ft. was obtained, which it is proposed to utilize for electric power purposes in operating the plantation mill and railway. Makaweli Plantation now has the best gravity supply on the islands, with a daily minimum, from its two sources, of

65 000 000 gal. It is proposed, later, to store the freshet waters in reservoirs, and to use them as balancing mediums to restore the supply when the streams run low. Owing to the steep land slopes, 6 to 15°, it is very difficult to select favorable reservoir sites, except in the center or back of old volcanic cones.

Many streams have been diverted and reservoirs made during the last five years on the Wailuku and Pioneer Plantations on Maui, the Oahu and Waialua Plantations on Oahu, and the Koloa, Makee and McBryde Plantations on Kauai; but, for the reasons before stated, practically no stream diversion for irrigation has been made on the largest island, Hawaii, except the development of water for cane-fluming purposes at Olaa, Pahala and Hutchinson.

Ground-Water.

The most novel development in water supply has been the discovery of water by driving tunnels into the lava formation at high altitudes in encouraging localities. It is very difficult to predict what success will reward any outlay in this field, as the results are all problematical. A 2 000 000-gal. flow has been developed at an altitude of 1 400 ft. at Waianae, on Oahu Island, by a 500-ft. tunnel; while at Lahaina on Maui, at an altitude of 2 600 ft., a 6 000 000-gal. daily flow has been developed by 2 600 ft. of tunnel in a formation the exterior surface of which showed no signs of water, such as springs, etc., and this volume has kept practically constant for two years, fluctuating slightly with the rainfall on West Maui Mountain, in its immediate vicinity, 3 000 ft. higher. On the other hand, in the fifteen miles of aqueduct tunnels, cut under the writer's supervision in the past two years, no ground-water in any quantity has been intercepted except an occasional drip from tunnel roofs through porous stone.

Duty of Water.

The quantity found necessary to irrigate each 100 acres is 1 000 000 gal. of water per day. Sugar cane is grown in furrows, about 5 ft. apart, into which the water is turned from the field ditches. When the seed is newly planted the water is turned on every 3 or 4 days, but, after that, an application of once each

10 days is considered sufficient. The above quantity, if applied uniformly to the whole surface, would make a depth of 134 in. in one year, excluding rainfall and evaporation, which is possibly 50 in. yearly in most of the irrigated properties. It means the application, for a crop period of one year and a half, of 22 800 tons of water per acre to produce 50 to 80 tons of cane, which would appear to be excessive.

It is safe to presume that leaky reservoirs, ditches and unequal and wasteful distribution prevent the application of not more than one-third of this quantity of water to the roots of the cane, where its value would be utilized.

Economies of various kinds in the application of water are now being gradually introduced, which will enable the best results to be obtained. Nearly all the water thus far developed has been used by the owners on their own property. Lately, surplus waters have been disposed of to adjacent owners, at a flat rate of from $8 to $10 per 1 000 000 gal. Great credit must be given the American pioneers who have developed such splendid supplies under so many adverse conditions in the past twenty years in those remote islands in the Pacific. By no other people, except perhaps the Mormon settlers of Utah, has so much enterprise been displayed, and so many sacrifices made in developing a non-productive country into one of pronounced prosperity.

TRANSACTIONS

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DISCUSSION ON
IRRIGATION.

By Sir Thomas Higham, Gen. F. H. Rundall, Messrs. C. J. Grant, Michael Elliot, Alfred Chatterton, Almon H. Fuller, H. D. Pearsall, L. J. Le Conte, David M. Duller, Sir Hanbury Brown, Messrs. Paul Levy Salvador and J. E. de Meyier.

Sir Thomas Higham, K. C. I. E., M. Inst. C. E., Bristol, England.* (By letter.)—The results attained by irrigation under British engineers in India and Egypt are so closely connected that Sir Hanbury Brown must be congratulated on the happy idea of placing them side by side in his interesting and instructive paper. The most important difference between the climatic and administrative conditions in the two countries has been well stated in the opening paragraph, but a more concrete idea of the comparative value of irrigation in Egypt and in India may be obtained by a consideration of the charges actually made for irrigation. Inasmuch as the payment of the land tax in Egypt conveys a right to a water supply, and the tax is entirely remitted in the event of a failure of the supply, the rate of this tax, which is said to average 15 shillings per acre, may be fairly regarded as the charge for irrigation. In India the charge for irrigation is not always taken in the form of a water-rate, payable by the cultivator on the area actually irrigated by him, and wholly distinct from the land revenue demand which is payable by the landlord; in many cases, this demand has been fixed with reference, among other things, to the water or irrigation advantages, and no separate charge is made for the use of the Sir T. Higham.

* Late Inspector-General of Irrigation for the Government of India.

Sir T. Higham. water; in other cases the charge for the water supply is taken, partly in the form of a water-rate, which is recovered from the occupier, and partly in the form of an enhancement of the land revenue, which is payable by the landlord. But whatever variations there may be in the forms of assessment and collection, the amount of revenue directly due to irrigation can be and is accurately determined, and regularly credited to the irrigation works in the annual accounts. These accounts show that the average charge for water supplied by major works, in 1900-01, to an area of over 11 000 000 acres, was at the rate of Rs. 3.5 or 4s. 8d. per acre; the range being from Rs. 1.9 in Sind and Bengal to Rs. 4.8 in the Bombay Deccan. The average rate realized on over 2 000 000 acres irrigated in the same year from minor works, the supply from which is more irregular and precarious than in the case of major works, was only Rs. 2.4 or 3s. 2½d. per acre. Thus it appears that the average rate per irrigated acre which can be realized in India is less than 30% of that which is paid in Egypt.

In the consideration of this average rate the question of lift irrigation may be of some importance. Sir Hanbury Brown claims, as one of the results of the works which have been carried out in Egypt, that there has been a diminution of the height through which water has to be raised for irrigation. This is undoubtedly the case, but it would be interesting to know the total area for which the supply has to be lifted (however small may be the lift), as compared with the area under flow irrigation, and the difference in the land-tax charges for lift and flow irrigation. The water-rate in India for lift irrigation is in some cases one-half, and in others two-thirds of that charged for flow, and there is, perhaps, a preponderance of official opinion in favour of the former or lower of these two proportions. The total area of lift irrigation on Indian canals is, however, so small, both relatively and absolutely, that it may be left altogether out of consideration. But it is believed that the area still under lift irrigation in Egypt is very considerable, and, as the cost of lifting has to be paid, in addition to the land tax, the price which has to be paid for irrigation in Egypt is so much more than the 15 shillings per acre which has been assumed above, although the difference is not paid to Government.

The author states that, as a result of the works undertaken since 1884, the cultivable area of Egypt has been increased from 5 000 000 to 6 000 000 acres, the value of land has been doubled, and, at the same time, the land tax has been reduced from £5 000 000 to £4 500 000, in round figures. This is a very striking result, but one conclusion, among others, to be drawn from it is that the Egyptian Government has not looked for any direct return on the 4 millions of capital expenditure which has been incurred, and that the whole

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of the profits of this new or improved irrigation has gone into the pockets of the landowners, who have, in addition, received the benefit of a reduction of half a million in the amount of the land tax. It is also stated that the land tax, as now assessed, is a little less than one-third of the renting value of the land, subject to a maximum limit of £1 12 6 per acre. In a paper by Sir William Willcocks, which was read at the International Engineering Congress at Glasgow in 1901, the area of cultivated land in Egypt proper is said to be 6 000 000 acres, of which two-thirds are rented at a mean value of £5, and the balance at a mean value of £1, per acre per annum. If the total amount of the land tax were no more than 4½ millions the rate would be a little more than one-fifth, instead of a little less than one-third, of the rental. Even the higher of these rates must appear remarkably moderate to an Indian administrator, considering that the whole cost of constructing and maintaining the irrigation works, exclusive of the arrangements for lifting, is borne by the State. It is not suggested that the land tax might or should be pitched at a higher rate, for the Egyptian Government no doubt takes as much as is necessary or expedient, and it is not difficult to find reasons for leaving to the owner of the land a larger share of the profits of irrigation than is customary in India. But the point is that the cultivator has to pay, in addition to the land tax and the cost of lifting, a net rent* to the landlord, which is not less than double the land tax, that is to say, not less on the average than 30 shillings per acre. This is certainly more than three times the average amount that an Indian tenant has to pay as rent, in addition to his water rate, which, as has been shown, also averages less than one-third of the Egyptian land tax. For all purposes of comparison the charges for land and water must be considered together, and it is, in fact, very difficult to separate them either in India or in Egypt. When account is taken of both, and of the cost of lifting, we are led to the conclusion that the Egyptian fellah is ready to pay nearly four times as much for an irrigated acre as the Indian rai'yat.

This difference in what may be called the market value of irrigation is, no doubt, mainly due to the difference in the climatic conditions of the two countries, to which the author has referred, but there are also other causes, such as the extraordinary fertilizing qualities of the Nile silt; the facility with which the produce can be conveyed to the seaboard and to European markets; the pressure of the population on the cultivable area, etc. But, whatever the causes, the result is the same. The demand for irrigation in India, keen though it often is in certain localities or at certain seasons, can never be as persistent, as intense, and as universal as it is in Egypt,

* By "net rent" is meant the gross rent less land tax, but in practice the latter is, of course, paid by the landlord, who receives the gross rent from the cultivator.

Sir T. Higham. nor can the cultivator afford to pay the same price for it. In India, irrigation is of the greatest importance as a means of rendering cultivation independent of the vicissitudes of the seasons; in Egypt, it is indispensable, for not merely the prosperity, but the very existence of the country as a civilized state is dependent on it, and has been so for more than 7 000 years. In India, the margin for new works which are likely to prove directly remunerative to the State is narrowing every year; in Egypt, it has not yet been approached.

Almost all future extensions of irrigation in India, with the exception of the large canals that are still possible in Northern India and in Sind, will involve the construction of storage works. Among all existing storage works there is none that can be compared for size with the great Assuan Reservoir, with its actual capacity of 35 000 million cu. ft., and its potential ultimate capacity, *pace* the Phil-Phylaeans, of 70 000 m. cu. ft. The Periyar storage work (to which reference is made on page 10) is the largest with a capacity of 6 480 m. cu. ft. The work was opened in 1896; in 1899 there was no overflow or escapage from the lake, but, in other years, the surplus is estimated to have averaged 10 000 m. cu. ft. Additional storage might apparently be provided here with advantage, but in years like 1899 there would not be water to fill it. The next largest work is Lake Whiting, which supplies the Nira Canal, in the Bombay Deccan. This lake has a catchment of 128 sq. miles, and a storage capacity of 5 300 m. cu. ft. As it is situated in the Western Ghats, where the rainfall is abundant, the supply can be relied on, but the lake did not fill in 1899, owing to the unusually early cessation of the rains; so that, although the escape sluices, which are kept open during the early floods, were closed before the usual date, there was not sufficient time to fill the lake. The water at Periyar and Lake Whiting is held up by masonry dams, the maximum heights of which are 156 and 126 ft., respectively.

A storage work is now under construction in the Mysore State, the capacity of which approaches more nearly that of the Assuan Reservoir. This work, known as the Marikanave Tank, has a catchment of 2 075 sq. miles, but within this area there are a great number of existing tanks which will reduce the run-off. The lake will have a capacity, when full, of 30 000 m. cu. ft., and a water-spread of over 40 sq. miles, and will be held up by a masonry dam, 142 ft. in height, above the bed of the Vedavati River, a tributary of the Tungabhadra. But it is estimated that the tank will not fill more than once in 30 years. The average annual rainfall is not more than 25 in., and the inflow, due to such a fall, will probably not exceed 10 000 m. cu. ft. In some years, it may be much less, or even *nil*. The reason for providing a storage capacity so much in excess of the average annual inflow is interesting. It was originally pro-

posed to provide a capacity of 20 000 m. cu. ft., which would about equal the inflow due to an annual rainfall of 30 in., but there were records of cyclonic rainfalls, the run-off of which would not only fill a tank of this capacity, but would also require an overflow capacity of 60 000 cu. ft. per sec. Such an escapage could only be provided by cutting a deep channel of adequate dimensions through hard rock, and, as a matter of arithmetic, it was found to be cheaper to increase the height of the dam, and to place the bed of the escape at a higher level. The physical conditions at this site are unusually favourable for the construction of a large storage work at a moderate cost per unit of capacity, but the great variation and irregularities of the rainfall will render the irrigating value of this work very uncertain. Sir T. Higham.

These three storage works are the largest and most important now existing or under construction in India for purposes of irrigation. Others have been proposed which more nearly resemble, both in magnitude and type, the great work at Assuan. Sites have been examined on such rivers as the Tungabhadra, the Kistna, and the Cauvery, in Southern India, with a view to the construction of reservoirs, the smallest of which would probably be given a capacity of not less than 30 000 m. cu. ft. During the monsoons of even the most unfavourable year, the surplus or unutilized supplies of these rivers would be ample to fill reservoirs of the capacity proposed many times over, but the conditions are much less favourable than on the Nile. During the first five months of the calendar year, the supplies in these rivers are normally not more than sufficient, and are often insufficient, to meet the demands for existing irrigation. The rivers are more or less in flood from the setting in of the southwest monsoon in June to the close of the northeast monsoon in December. During this period the surplus available for storage is enormous, but there are great variations, not only in the absolute amounts, but also in the periods of their occurrence.

For the Cauvery, there are records extending over 24 years from which the surplus from June to December has been estimated as varying from 72 to 670 milliards (a milliard representing 1 000 million cu. ft.), the average for the 24 years being about 210 milliards. The minimum amount would suffice to fill two reservoirs of the capacity of that at Assuan (35 milliards) once, but, in order to make the filling of only one a certainty, it would be necessary to commence impounding very early in the flood season. Thus, in 1899, the total surplus available after July 31st did not exceed 16 milliards, of which only half a milliard was available in August, and the balance in September, after which there was no surplus at all. An examination of the records shows that a full reservoir cannot be relied on, if impounding begins later than July 15th. There

Sir T. Higham. is no month after this in which the surplus is not likely to fail absolutely, and there is also none in which high floods are not likely to occur. Conditions in this respect are more favourable in the case of the proposed reservoirs on the Tungabhadra and Kistna, as it will not be necessary to fill the largest reservoirs that are likely to be proposed before the end of September, unless for the purpose of high-level irrigation. But it may be too late to fill them if impounding is deferred until October, although high floods sometimes occur in that month, and there is often a considerable surplus until the end of December.

At Assuan the high and heavily silt-laden Nile floods are passed through the open dam, with no greater heading up than is sufficient to produce the required velocity through the under-sluices, and impounding does not begin until after the last flood of the season has passed, the reservoir being filled during November, December, and January, when the water is so clear that the danger of silting must be regarded as very remote. On these Southern Indian rivers, the flow of which depends on the rainfall in the neighbouring ghats, and not on the overflow of great equatorial lakes more than 1 500 miles away, impounding must commence long before the flood season is over, so that heavy floods will often have to be passed through full or nearly full reservoirs. It may be possible to pass such floods without danger, if ample sluiceway be given, and other necessary precautions be taken, but it will be difficult to prevent very heavy silting in the reservoirs. This silting will not only shorten the life of the reservoirs, but will also deprive the water of its fertilizing sediment. The author has shown how the lands at the lower end of the chain of basins in Middle Egypt lost in productiveness from being deprived of the rich Nile deposit, though they gained a better and more regular water supply from the Ibrahimia Canal, and the quantity of Cauvery silt deposited by irrigation is one of the principal factors in the value of lands in the Cauvery Delta.

The author has briefly alluded to some of the difficulties connected with storage. These difficulties attend the construction of storage works in all parts of the world, but over and above these difficulties certain risks have to be faced in India, which do not present themselves in works dependent on the ever regularly flowing Nile. In the case of the smaller works, there is always the risk that in a dry year, when irrigation will be most urgently needed, the supply available within the catchment will be below the full capacity of the works; in the case of the larger works which may be proposed on the great Southern Indian rivers, the absolute surplus will always be more than sufficient, but there is the obligation of keeping the reservoirs more or less filled throughout the greater part of the flood season, in order to avoid the risk of the rivers' falling before the reservoirs are full.

One of the most signal triumphs of the British Canal Administration has been the abolition of the Corvée, or the substitution of contract for forced labour in the annual silt clearances. This great reform has been rendered possible partly by the introduction of a higher standard of intelligence and honesty in the superintendence of the clearances, and partly by the reduction in the volume of silt to be cleared, which has been one result of the progress made in perennializing the irrigation. In respect to the latter point, a few remarks on Indian experience may be made. The inundation canals in the Punjab and in Sind, which are mere open cuts drawing their supplies from the River Indus or its tributaries during the flood season, almost invariably silt heavily, and the annual clearances of their head channels form the most important factor of the cost of maintaining these irrigation systems. Annual silt clearances are, however, almost unknown on the great perennial canals, although there are heavy silt deposits in many of them during the flood or monsoon season. The inundation canals, which, in this respect, are the counterparts of the feeder channels which supply the basins on the Nile, cannot work after the river falls, and are then closed for the silt clearances which will enable them to run in the following monsoon. But on perennial canals the whole of the clear cold-weather supply of the river is diverted into the canals by the head-works, and, if run in strong flushes, picks up and carries forward the silt that has been deposited by the heavily silt-laden monsoon supplies. Some of this is deposited in the tails of the branch canals, or in the distributaries, and small clearances are occasionally required on these, which, however, cost little and present no difficulty. But on all these perennial canals, with but one or two exceptions, silt clearances at the head, either with dredgers while the canal is running, or by spade and basket-work during closures, is practically unknown. A notable case is that of the Sirhind Canal in the Punjab. This canal, which was opened in November, 1882, was designed to carry a maximum supply of 6 000 cusecs, in a main line, 40 miles in length, with a bed width of 200 ft., and a bed inclination of 1 in 8 000. It was found that silt was deposited to an alarming extent during May, June, and July, that the deposit, which was generally at a maximum at the end of July, remained more or less constant during August and September, but that the greater part of it was scoured away by the full supplies of clear water which were run during October, November, and December. From January to April very little scour was effected, and, in May, silt deposit began afresh. This cycle was continued year after year until 1893, but, as a matter of fact, the silt had been gradually growing, the quantity scoured away in one scour season being always somewhat less than the quantity deposited in the preceding silting season. Local con- Sir T. Higham.

Sir T. Higham. ditions would have rendered any attempt to redress the balance by means of dredging very difficult and expensive, and it was eventually decided to try the effect of closing the canal entirely during May, June, and July, 1893, so as to eliminate altogether one silting season. The experiment was made with some hesitation, as it was likely to involve the entire loss of the crops, sugar-cane, cotton, rice, etc., which are sown during this period of the year. Fortunately, this result did not follow, for there happened to be very unusual rainfall at the most critical times, and the usual sowings were successfully completed without the help of canal water. During the closure there was, for the first time since the canal had been opened, a clearance by basket-work of a certain amount of silt which had accumulated in a very awkward place, and, in the following cold weather, certain works were remodelled with the general object of strengthening the tendency to scour, and of weakening the tendency to silt, so as to balance the one more effectually against the other. The head regulator, which had been originally designed to draw off the supply at the bottom of the vents, was altered so as to take in top water, and the capacity of an escape which had been constructed in the twelfth mile was increased, so that strong flushes of clear water, greatly in excess of the actual demand for irrigation, might be passed down to this point, whenever the water was available, the excess being passed out at the escape. The measures taken proved successful; the canal is sometimes closed for 24 hours or more during the passage of very dirty floods, but otherwise it has been run regularly whenever there has been a demand, and after eight years' working the quantity of silt in the bed at the end of the silting season was less than had ever been recorded. The tendency of this canal to silt has caused great anxiety, and still requires close watching and careful regulation, but apart from the special expenditure incurred in 1893-94, hardly a rupee has been spent, either before or since that year, in removing silt from the main canal; reliance is placed entirely on the scouring efficiency of the clear-water flushes during the cold weather.

The only other work on which much trouble has been experienced with silt in the head reach is the Sone Canal in Bengal. On this canal the silt deposits have been so heavy as to interfere not only with the supply, but also with navigation, and to necessitate annual clearances, which were partly effected by hand during closures, but mainly by expensive dredging when the canal was in flow. Up to about ten years ago the annual charges for dredging on this canal, including repairs of the plant, but not interest and depreciation charges on its cost, averaged over £5 000, but they have since been reduced to about £900, by the adoption of measures similar to those which were taken on the Sirhind Canal. The cost of hand clear-

ances has also been materially reduced, and most of the silt is now removed by strong scouring flushes during the cold weather. On the Orissa Canals an expenditure of about £1 000 per annum is also incurred on silt clearances in the head reaches, but with these exceptions the cost of such clearances on the perennial canals is practically *nil*. It can hardly be doubted that the extension of perennial irrigation in Egypt will lead to a further great reduction in the volume of the clearances, and that the clear water collected in the Assuan Reservoir will do a great part of the work which was formerly carried out under the barbarous Corvée system. Sir T. Higham.

The efficiency of a canal depends very much on the degree of perfection attained in its distributary system. When irrigation works were first undertaken in Northern India, it was considered sufficient for the Government to construct the main canal and a few branches (the latter with a capacity seldom less than 500 cusecs.), and to leave it to the villages concerned to make their own water-courses, some of which were of considerable size, and many miles in length. The great disadvantages of this system were, however, soon apparent, and little time was lost in providing each canal with a system of "rajbahas," or small service canals, with capacities varying generally from 20 to 150 cusecs., which took off from suitable points on the main canal or the branches, and were carried out, right and left, into the country, following the minor ridges. The village water-courses took off from these rajbahas, and, in course of time, all outlets in the banks of the main canal and principal branches were removed. Even so it was found that the water-courses, or private channels, were of inconvenient size and length, and, what was more objectionable, that the water-course of one village had to be carried through the lands of another. Many of the rajbahas on the new canals were also of greater size than was formerly considered expedient, the capacity of some ranging from 300 to 400 cusecs. It was thus found desirable to provide all but the smallest rajbahas, or, as they are often called, all "major distributaries," with a number of "minors," or subsidiary distributaries, with capacities varying from 5 to 20 cusecs., which took off right and left from the parent rajbaha, and carried the distribution further afield. This system was first carried out on an extensive scale on the Sirhind Canal in the early Eighties, the general principle being that the minors should convey water to the boundary of every irrigating village which was not itself traversed or bordered by the parent rajbaha, and should be so aligned that the length of no water-course should greatly exceed one mile. The heads of the village water-courses, or "outlets," were placed sometimes on the minors, and sometimes on the parent rajbaha, as convenient.

The extension of this system has led to a great increase in the

Sir T. Higham. mileage of distributing channels for the construction and maintenance of which the Government is responsible, but it has reduced *pro tanto* the expenses of the cultivators, and the greater economy in distribution which has resulted is well worth the extra cost. On the more recently constructed canals the principle of maintaining control over the distributary system as long as possible has been carried still further, and the canal officers have undertaken the alignment, grading, and even the construction of all the village water-courses, the actual cost of construction only being subsequently recovered from the cultivators by easy instalments. The practice on the Chenab Canal, which is now followed in all cases when irrigation is extended into Crown waste lands, deserves notice. Sir Hanbury Brown has stated how these lands have been divided on the ground into squares of 1 100 ft. side, each square constituting a peasant holding of nearly 28 acres, being demarcated by four corner blocks, with their upper surfaces nearly flush with the ground surface. The reduced levels of these surfaces and of points midway between them are determined by native surveyors, and from the levels thus taken at 550-ft. intervals a large-scale contoured map of the whole area is prepared. On these maps, upon which the squares or future holdings have also been plotted, the engineers first lay down the traces of the major and minor distributaries. The holdings or squares are then divided into groups, and to each group is assigned its own water-course, the grading, alignment, and capacity of which are shown on the plan, and are so arranged that every square in the group shall be brought under effective command. The natural drainage lines, as indicated by the contours, are also laid down on the map, and each forms the boundary of irrigation from the distributaries or water-courses to the right and left of it. It is a cardinal principle that no water-course should cross a drainage line, and a certain width along all well-defined drainage lines is reserved as common land, so that the drainage may not be obstructed by cultivation. Finally, the boundaries to be given to the new villages are laid down on the maps. A village usually comprises from 100 to 200 squares, and is normally bounded on one side by a distributary, following a ridge line, and on the other by a drainage line, the transverse boundaries being laid down as most convenient. A copy of the map is then made over to the civil officer, who arranges for the introduction of colonists, allotment of holdings, etc., the canal officer proceeding in the meanwhile with the construction of the distributaries and water-courses, so that by the time a settler arrives everything is ready for delivering water to his holding. Thus the distributaries, the cultivators' water-courses, and the village boundaries are all aligned, the village sites, roads and common lands are all located, primarily with reference to the

ground contours, and so as to afford the greatest facilities for irrigation and drainage. When irrigation is extended to villages already in existence the canal officer has not, of course, so free a hand in controlling the arrangement of the network of distributing channels, and must be content with the nearest approach to the ideal standard that may be possible. The main point is to keep the supply undivided and under the canal officer's control as long as possible, so as to minimize the waste and loss which occur after the water has passed into the consumers' water-courses. Sir T. Higham.

As stated in the paper, great storage works are required for any considerable extension of irrigation in the tracts which are most exposed to famine. Much, however, still remains to be done in the construction of canals that will draw unfailing and perennial supplies from the snow-fed rivers of the Punjab. A perennial canal from the left bank of the Indus, which will reclaim the large desert tract known as the Sind Sagur Doab still remains to be constructed, but this project, important as it is, must be regarded as much less promising than the great Upper Jhelam and Chenab scheme, which is now being estimated for in detail, and will probably be the next work undertaken in this province. Of the five great tributaries to the Indus from which the Punjab derives its name, as "the land of the five rivers," the three most westerly are the Jhelam, the Chenab, and the Ravi, from the left banks of which have been taken off the three canals known respectively as the Jhelam, the Chenab, and the Bari Doab Canals. Up stream from the two former, and down stream from the last, there are large tracts to which irrigation can be most advantageously extended, but the existing canals already exhaust the cold-weather supplies of the Chenab and the Ravi, and new canals for which supplies could be relied on only during the monsoons would not be remunerative. On the Jhelam, however, there is a cold-weather surplus which would ordinarily be sufficient for the cold-weather irrigation of the three tracts referred to. It is proposed, therefore, to tap the Jhelam River some miles above the head of the present Jhelam Canal, and to divert its cold-weather surplus into the Chenab by a feeder canal, which will skirt or pass through a range of low hills, and will irrigate a considerable area between the two rivers. The Chenab River, with its supply thus reinforced, will also be tapped some miles above the headworks of the present Chenab Canal, by a large new canal, which will irrigate a tract outside, or to the south, of the present Chenab Canal tract, and will then be continued across the River Ravi (which will probably be crossed by a siphon) into the lower part of the tract lying between the Ravi and the Sutlej Rivers. This bold scheme is likely to cost not less than £5 000 000, but it is anticipated that nearly 2 000 000 acres will be irrigated annually. If the capital cost does not exceed

Sir T. Higham. £3 per acre annually irrigated, the work should prove directly remunerative as a financial investment, irrespective of all other advantages which will result from its construction.

Gen. Rundall. GENERAL F. H. RUNDALL, C. S. I., R. E., Llanbedr, North Wales.* (By letter.)—The following remarks are submitted by the writer, whose experience of 30 years in India enables him to confirm very much of the contents of Sir Hanbury Brown's paper, especially as regards the irrigation works in India. He has also a slight acquaintance with some of the works in Egypt, having been summoned during the viceroyalty of the late Ishmael Pasha to inspect the Barrage across the Nile at Cairo, then in a precarious condition, and to advise remedial measures.

The general summary as regards India gives a good idea of the various large works already in operation. The enormous size of the Delta works in the Madras Presidency, with their simple constructions, testifies to the boldness of their chief designer, while their economy of construction and efficiency in working have not yet been equalled in any other country. There is one peculiarity in their design which has not been touched upon in Sir Hanbury Brown's paper, and that is the construction of facilities for navigation with irrigation. It seemed almost impossible to persuade the Government of India, in that day, of the importance of cheap water-carriage; and it was with difficulty that such a combination was sanctioned in some of the subsequent works in Upper India. The success which has followed the Madras Delta systems was not attained in a similar degree, and the great "Chenab" works, described on pages 12 and 13, have been totally unprovided for with water transit. Consequently the cry has been raised that while the output from the irrigation works has been enormous, no provision has been made to carry away the surplus produce! A remedy has now been proposed, *viz.*, to provide a railway through the heart of the irrigated tract for the purpose.

In the report which was originally drafted in 1874 by the Inspector General of Irrigation, in obedience to the order of the Government of India, enumerating the series of projects which still remained to be carried out, the necessity for combining navigation with irrigation was not forgotten; but at the time, the Chenab scheme, together with several others, was looked upon as much too large and grand to be attempted, and so when finally plans and estimates were ordered to be prepared for that scheme, the original suggestion for a combination of navigation works was omitted.

It is necessary here to remark that the proposal for navigation works was never to be restricted to isolated schemes, but a great highway was contemplated which should be connected with the

* Late Inspector-General of Irrigation for the Government of India.

various lines already partially ready, and which should eventually reach the sea at the Port of Calcutta, from whence the surplus produce of all the intermediate systems, after distribution *en route,* could be exported. Whether in the future this great line of intercommunication by inland waterways will be undertaken, it is impossible to predict. Gen. Rundall.

Had America been as slow in her appreciation of cheap carriage, the great projects of improved communications which have of late years been proposed (quite irrespective of the immediate financial return, by abolition of all tolls, the far-sightedness of the American Government looking for their returns from the general increasing prosperity of the country), would probably have never seen the light. Hence it is quite within the limits of possibility that the Government of India may similarly awake to the necessity of providing a grand line of water communication from the Chenab to the sea.

The original idea of providing water for irrigation only, over large tracts in India, took no account of providing for drainage at the same time, and consequently on the Ganges Canal the soil became water-logged, the distributaries having been aligned across the depressions on the line. This defect was subsequently altered, and, in subsequent projects, received due consideration.

In deltas where the rivers run on the highest level, and the high floods overtop the natural banks, artificial levees have been raised as on the Mississippi.

The financial success of the various works estimated from the receipts of water rates alone, and considered to be the main point in regulating the supply of funds for the cost of new works, was another of the fallacies of the Government; at least, the increased prosperity of the population, gauged by the increase of the general revenue, was never credited or attributed as the result of the works. Since the advent of Lord Curzon to the Viceroyalty, this shortsighted policy has been set aside and the word has gone forth that henceforth the construction of new works is not to be restricted to the value of the water rate only. It is therefore hoped that the more enlightened policy, such as has guided the American Government in the improvement of their waterways, will be carried out.

In designing irrigation schemes on a large scale, therefore, the five following points must always be considered:

1.—The requisite quantity of water for irrigation;

2.—Drainage for the disposal of such water after the crops have been supplied;

3.—Navigation of the cheapest kind (free from tolls, if possible) for the conveyance of surplus produce;

4.—In the case of delta schemes, protection from flood by embankments;

Gen. Rundall. 5.—In estimating the returns on the capital expenditure, the effect on the general prosperity of the inhabitants of the irrigated tracts and not the mere value of the water rate should be considered.

There is an error in Table 1, in the figures shown in the first column for Bengal.

The area of food grains insured by the canal schemes should be, at the least, 2 000 000 instead of only 650 000 acres.

Mr. Grant. C. J. GRANT, ASSOC. M. INST. C. E., Mildura, Victoria. (By letter.)—Quoting from the paper on "Irrigation under British Engineers" by Sir Hanbury Brown:

The problem "To secure an economical and just distribution of the water" (page 21) was solved "mainly by an impartial and rigid application of a well-considered rotation programme" (page 22), by so doing "a high 'duty' has been got out of the water" (page 22). "The land tax * * * is fixed at a little less than one-third of the renting value of the land, subject to a maximum rate of £1 12 6 an acre. The average land tax is 15 shillings an acre" (page 4). "It is water that is wanting, and to find it is the present-day Soudan question" (page 31). "The allowance of water for cotton should be 1 000 cu. ft. per diem per acre of crop, and for rice double that amount (page 22).

These statements show that the great irrigation problem of the Soudan is the finding of ample water for the land available; that the extension of irrigation is not limited by the area of land, but by the amount of water available; that careful observations have been made of the actual requirements of various crops; and that, by efficient control of the water during distribution, high duties have been obtained.

This all tends toward economy in the distribution of water, but the method of charging per acre is not consistent with rigid economy in its use by individual consumers. Actual measurement of the amount of water supplied to irrigators and charge according to measurement are essential to rigid economy in the use of water. With actual measurement, the irrigator knows the amount of water he uses, and thus is enabled to work in a more scientific manner. Over-watering, often harmful in itself, is largely due to a lack of knowledge of the amount of water used. With an average water rate of 15 shillings per acre, the value of preventable waste would speedily repay the cost of installation and maintenance of a system of measurement, local experience going to show that meters, suitable for the measurement of streams, usually handled during distribution, can be installed for a sum covered by the savings effected in from two to three years.

The water saved could be applied to further areas of land, the increased value of which would be very great compared with the

cost of measurement, and in this way further millions could be added to the value of landed property in Egypt. Mr. Grant.

MICHAEL ELLIOT, ASSOC. M. INST. C. E., Melbourne, Victoria. (By letter.)—The writer's experience of Egypt and its irrigation works dates back to 1880 and extends to 1884, at which date Sir Hanbury Brown's experience began. At the close of the Nile Expedition of 1884-85, in which the writer had the honour to take part, it was his impression that Egypt was a doomed country. Mr. Elliot.

It is pleasing to know from Sir Hanbury Brown's paper and other sources that so much has been accomplished by British engineers and to tender to him and others hearty congratulations on the success of a noble work carried out with indefatigable energy and honesty of purpose.

The author might have made some reference to those engineers who had proposed the works which he has had the opportunity to carry out. It must be evident to him that without the British occupation of the country, it would have been impossible to have accomplished anything. He must be aware that Sir John Fowler proposed to strengthen the Nile Barrage in the Seventies; also, that storage on the Nile was discussed vigourously before 1884. The debate as to the Wady Rayan storage and the dam on the Nile at Assouan had been going on for years previous to 1884.

In the writer's opinion, which is expressed with due deference, there should have been either no Philæ, or else no Assouan Dam. When it was decided to maintain the Temple of Philæ, a fresh site should have been sought for the reservoir, and a better site could have been obtained at Wady Halfa. The writer has often viewed the Nile from the then terminus of the Halfa and Khartoum Railway and thought what a favourable site for storage it formed. Of course, these impressions may be unsound, when compared with results obtained by surveys.

The writer was always unfavourably impressed by the Wady Rayan project and is more so after reading the paper stating that the reservoir is only capable of holding an available supply of 2 000 000 or 3 000 000 cu. m. above draw-off level. The loss by evaporation and other causes would be considerable, and it is only reasonable to ask whether there would be anything left?

Judging from the statement on evaporation, made in the paper, it appears highly probable that very little of the 3 000 000 cu. ft. stored would reach the cultivator.

The author does not furnish any statement of cost of this work, but from the writer's recollection it would be very considerable, and it is possible that more profitable sites will be found on the river itself.

As to the Nile Barrage itself, it is well-located, well-designed,

Mr. Elliot. and well-built, and reflects the highest credit on all concerned, except as to the previous reservations.

In reference to the Assiout and Zifta Barrages, there is an opening for expression of opinion. One cannot be sure that the heavy masonry superstructure is the best design for a class of work necessary to hold up a head of 9 ft. 9 in. Before going further the writer must praise with unstinted measure the design of the foundation, and would like fuller information on the design of the iron piles and the manner of grouting the joints.

After the foundations, the design could be improved by making the superstructure of iron framing, so as to convey the pressure to the foundations vertically instead of maintaining it horizontally against the superstructure. This design would be more economical and would reduce considerably the pressure on the foundations.

Sir Hanbury Brown's remarks relative to storage in the Victoria Nyanza are of great interest. That nine-tenths of the rain falling on the lake itself is dispersed by evaporation and absorption is somewhat startling and disappointing. Turning up old accounts by explorers, the writer finds that exactly the same amount is stated, *viz.*, 4.4063 ft. falling, 3.9371 ft. evaporated. It would be interesting to know whether these figures have been verified by recent observations, and over what periods the rainfall and discharge of the lake has been gauged.

The lake is stated to cover an area of 26 000 sq. miles and the catchment three times that area, which makes a total catchment of 104 000 sq. miles, forming an enormous catchment with a very fair rainfall. The writer has not been able to ascertain whether the Victoria Nyanza is deep or shallow, and it would be interesting to know what effect a considerable reduction in its area would have on the discharge of the Nile.

Suppose, for instance, a discharge outlet was constructed at the Ripon Falls and the lake gradually drained down. For a number of years the supply in the Nile would be augmented, and, eventually, the evaporation caused by the lake would be decreased. These suggestions are made without any data, and can only be valued as such.

In reference to the "Sadds" area, would it not be possible to plant these with trees, such as the willow, or other vegetation, that will thrive in a wet soil. There is a tree in Australia, called the Ti-Tree, which grows luxuriantly in swamp and would form a dense growth which would catch the detritus and probably raise a bank by this means.

Prof. Chatterton. ALFRED CHATTERTON, ASSOC. M. INST. C. E., Madras, India.*—The papers on this subject, as presented to this Congress, deal with irrigation in the United States, France, India, Java, Egypt and

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Hawaii, and contain much information that is both useful and interesting to irrigation engineers. Obviously it is impossible to discuss them in detail, and the remarks of the speaker will be confined to principles and points of general interest which underlie all irrigation practice. Local conditions, physical, economic and political, exercize a controlling influence over the design of irrigation works and the engineer can only be completely successful who brings to his work a thorough knowledge of the circumstances under which it is to be carried out and a clear idea of the agricultural needs of the community for whose benefit it will subsequently be operated. Similarly, criticism without such knowledge loses much of its force, and it is hoped that the present opportunity will be taken to bring forward for discussion some of the more urgent problems in irrigation engineering which are of international interest. Prof. Chatterton.

The papers disclose the fact that a great many units of measurement are in use, and that the duty of water is stated in very different ways. The primary unit used by English-speaking engineers is the foot, and, that used, practically, by all other engineers is the meter, and it would be a very good thing if engineers could agree upon some uniform system of recording irrigation data and obviate the inconvenience entailed by the use of a great variety of local units. "Acres per cusec," "liters per second per hectare," "miner's inches," "gallons per day" and "acre-feet" are samples of the terms which have come into use, and although the conversion of results stated in one set of units into those of another is a simple matter, yet it often involves a great deal of trouble, and it is certainly desirable that some agreement should be reached as to the use of a common system of units. For English-speaking engineers, the measurement of flowing water in cubic feet per second, abbreviated into cusecs, is the most convenient unit that can be adopted, but the cubic foot is too small a unit of capacity when applied to large storage reservoirs. The speaker prefers the acre-foot, equal to 43 560 cu. ft., or very approximately, to the flow of 1 cusec. for 12 hours. Not only is the acre-foot a unit of convenient size, but its use renders it comparatively easy to deduce some idea of irrigating capacity from the volume of water stored.

The progress of irrigation in many parts of the world during the last few years has been extremely rapid, and, year by year, the capital outlay expended on hydraulic works has been steadily increasing. In some countries, such as India, nearly all the easily available sources of water supply have been utilized, and much-needed future extensions of irrigation will involve the construction of large and costly engineering works. To obtain the benefits of irrigation on the widest possible scale, the highest technical skill will have to be devoted to the details of designs, and, in some directions, it will be

Prof. Chatterton. necessary to obtain more accurate data than are now generally accepted. This is especially true in regard to the empirical formulæ now used in calculating the velocity of flow of water under given conditions, such as obtain in big canals and tunnels, or through masonry sluices of large size. Experiments made in India and elsewhere with accurate instruments for measuring the flow of water past a cross-section have conclusively demonstrated that the usually accepted values of the coefficients in the formulæ of Bazin and Kutter give discharges considerably smaller than are found in actual practice, and, as a natural sequel, canals are now carrying much larger quantities of water than was originally contemplated. Owing to this initial error, losses by seepage and evaporation have in many places been greatly underestimated, and a more general appreciation of the fact that canals are usually carrying more water than they were designed to carry, will ultimately lead to a prevention of the hitherto unsuspected losses, and thus to an increase in the duty obtainable from the water.

Similarly, recent measurements of the discharging capacity of large and well-designed masonry works indicate that the generally accepted values of the coefficients of discharge are too small, and that they too require revision. Further, it is almost certain that no two hydraulic engineers would agree as to the dimensions of a rock tunnel to carry a given quantity of water under specified conditions as to slope, head, etc. The importance of more accurate information on these points scarcely needs emphasis, and the speaker suggests that it would be appropriate to establish an international committee to collect new data.

Irrigated lands which derive their water supply from rivers owe much of their fertility to the annually recurring deposits of silt which are brought down during floods, but comparatively little is known as to which of the constituents of the silt are of manurial value and which are worthless. In this direction there is much useful work to be done by the agricultural chemist in conjunction with the irrigation engineer. Some information on this point is very desirable in view of the fact that it is proposed to construct on some of the big rivers of Southern India high dams to form large storage reservoirs which will be kept full of water during the flood season to supply high-level canals, and the dams, during this period, will act mainly as diversion weirs, whilst, after the floods have passed, the water stored in the reservoirs will be passed down the river to supplement the supply to existing irrigation works lower down. The silt-laden floods will practically find in these reservoirs huge settling tanks in which will be deposited a considerable proportion of the solid matter, and the question has been raised as to whether it will affect the fertilizing value of the flood water passed

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over or through the dam. Probably very little of real value will be withdrawn from the water, but it would be satisfactory to have more definite information on this point, and, in any case, there remains the problem of how to maintain a permanent regime in the reservoir by getting rid of the silt deposited during the floods after they have passed away. Possibly floating hydraulic miners worked by electricity generated at the dam will be found of great use in washing out the huge banks of soft silt which every year will form on the slopes of the reservoir. Lastly, the question of keeping silt-laden water and sand out of irrigation canals is of prime importance on some rivers, and a comparison of the results obtained in different parts of the world by different methods might lead to great improvements.

These are but some of the problems confronting irrigation engineers, and the speaker thinks that it would not be difficult to make out a *prima facie* case for the formation of an international association of irrigation engineers, which might meet from time to time in congress to bring forward the results of their experience and submit them to discussion. No doubt there would be difficulties in the way of carrying out such an idea, but doubtless they could be overcome if the arrangements were undertaken by the American Society of Civil Engineers and the Institution of Civil Engineers conjointly.

In the paper by Sir Hanbury Brown on "Irrigation under British Engineers," it is stated that "wells can hardly be regarded as irrigation works in the ordinary sense of the word," and that, notwithstanding the fact that over 13 000 000 acres are irrigated by them in India. They are probably over 2 500 000 in number, and it is estimated that not less than 50 000 cu. ft. per sec. are drawn from them by some 6 000 000 cattle which do effective work equal to the continuous operation of 170 000 h. p. These are big figures, and, in view of them, the speaker would prefer to say that wells are at present among the most important of irrigation works, but that hitherto they have been almost entirely neglected by irrigation engineers. The Indian Irrigation Commission was of opinion that a great deal could be done to extend cultivation under wells, and, in the Madras Presidency, the Government has taken the matter up, and experiments and enquiries are in progress, which it is hoped will lead to important developments in this direction. It is thought that many of the wells have not been sunk to a sufficient depth to tap properly the supplies of subterranean water available, and it has already been proved beyond reasonable doubt that mechanical appliances driven by steam engines, oil engines, or electro-motors, can replace with advantage the ingenious though extremely primitive indigenous water lifts which are invariably worked by cattle power, or human labour. Provided with sufficiently powerful pumping

Prof. Chatterton. machinery it would be possible to sink wells to a much greater depth than is the prevalent practice to-day, and as the cost of lifting water would be but little more than one-half what it is now, it ought to be feasible to raise water from much greater depths than at present is considered practicable. The most valuable crops are grown and the best cultivation in India practised under well irrigation simply because no other course would pay, and future progress in the utilization of underground water supply must be accompanied by agricultural development. From the last census returns of the United States, it appears that there are over 150 000 acres under well cultivation in California, and everyone acquainted with the orange groves and fruit gardens of that State will admit that there, where the cost of obtaining water is so extremely great, agriculture, irrigation and agricultural engineering have reached their highest development.

Prof. Fuller. ALMON H. FULLER, ASSOC. AM. SOC. C. E., Seattle, Wash.*—Professor Chatterton mentions the efficiency of water coming from wells. No one will question but that the extra care with which the limited supply is handled adds greatly to its usefulness. But there may also be other reasons for that. About a year ago the speaker visited the Moxee District of the Yakima Valley in the State of Washington. He noticed that many were using the flow from artesian wells for irrigation, and that they seemed to be particularly well satisfied with the supply and its results.

The fact that they were independent of breaks in canals and of the control of head-gates gave them a feeling of independence not enjoyed by all users of ditch water. A still greater advantage claimed was that the temperature of well water coming from a depth of about 800 ft. was perceptibly higher than that of canal water fed by mountain streams, and, therefore, did not have a tendency to chill the crops that the colder water did.

In 1901† there were about 20 flowing wells in the district, within an area of about 6 sq. miles, yielding an average flow of about 0.7 cu. ft. per sec. from a depth of about 800 ft., with a temperature usually above 70° fahr.

Although the relative temperatures would not vary as much in India as in Washington, the speaker would like to inquire if the effect of different temperatures was noted and with what conclusions.

Mr. Pearsall. H. D. PEARSALL, M. INST. C. E., London, England.—Mr. Salvador says, on page 123:

"It is generally necessary to raise the water by mechanical means and to force it to a certain distance. Sometimes the fall is used to run some lifting machinery, such as hydraulic rams."

* Prof. of Civ. Eng., Univ. of Washington.

† U. S. Geol. Survey, Water Supply and Irrigation Paper No. 55.

Mr. Pearsall.

The speaker would now suggest that Mr. Salvador add particulars of the kind of rams used, the areas irrigated, and the amounts of lift and fall.

Irrigation of any considerable area requires a large quantity of water, and the hydraulic ram, as commonly known, deals only with very small quantities. Mr. Salvador, therefore, probably refers to irrigation of small plots of ground only.

It is, however, quite possible to use the hydraulic ram for irrigating large areas, and the speaker believes that it will be used for that purpose before long in the United States. He, himself, designed some machinery several years ago, which is, in principle, nothing but a large hydraulic ram, but of entirely different construction. This machine pumps a quantity of water greater than that pumped by any hydraulic ram previously constructed. This machine has been at work in Pennsylvania for 15 years. It is not used for irrigation, but it is well adapted for such use, and, on account of its construction, there appears to be no practical limit to its size. It is believed to be the only machine on the principle of the hydraulic ram of which this can be said, and the only successful one dealing with the quantities of water needed in extensive irrigation.

The large ram referred to is at the Isabella Furnace, Barneston, Pa. It uses a little over 1 000 gal. per min., and its efficiency is 72 per cent. The water used has a fall of 17 ft. and raises 125 gal. per min. to a height of over 100 ft. The speaker thinks that, where it is desired to lift water for irrigation, a similar machine would certainly afford an extremely convenient, economical and efficient way of doing so. Several similar machines have been constructed since this one was installed and have resulted in so many improvements in detail that the Barneston ram is not by any means mentioned as a sample of what can be done in this way, but because it has a long record of successful work. Much more work, and at less cost, can now be done by machines of the same general type.

Much larger machines of this type have also been made in England, with main pipes up to 2 ft. in diameter, and using many times the quantity of water before mentioned.

Moreover, for irrigation purposes, it generally happens that both fall and lift are much less than at Barneston, and these circumstances allow of considerable further simplification of the design.

What appears to be worth pointing out, however, is that, though the hydraulic ram has not been used (with the above exceptions) for large quantities of water, it may be so used; and that the principle of the hydraulic ram is, therefore, not to be judged by reference to the ordinary ram of commerce. That machine is an efficient one in very many cases when used for small quantities of water, but the fact that attempts to use it for larger quantities have failed has

Mr. Pearsall. now been proved to be due not to the principle itself, but to the methods used in carrying it out. Nearly all ram patents which have been taken out for a century have been merely for minor modifications of the original Montgolfier design. No previous thorough study of the ram appears ever to have been made, but this was necessary before so great an enlargement of its scope could be successfully accomplished. This study naturally led to radical alterations of design and many unforeseen developments. One result of such a study has been to shew that the principle is actually more suited in some ways (instead of less) to large rather than to small volumes of water.

Mr Le Conte. L. J. Le Conte, M. Am. Soc. C. E., Oakland, Cal. (By letter.)—Mr. Mead brings out a most important and true feature when he states that there is a great tendency to magnify the importance of engineering construction in irrigation problems. The whole financial success of any given scheme is entirely dependent upon the agricultural and economical sides of the question, which can only be satisfactorily worked out by experience. Another most important feature is the fertilizing value of the waters. This has a permanent value which cannot be overestimated. Irrigators can well afford to pay ten to twelve times as much for warm rich silt-bearing waters as for the clear cold waters from the mountains. The former not only irrigates the land, but replenishes the soil with a fertilizing sediment, the true value of which is immeasurable. These factors are what tell in the long run.

The pioneer irrigation engineers certainly deserve much credit for the good work they have done under the most trying financial circumstances. Cement and concrete are now looming up as very important factors in all new works as well as for repairs on old works. Where bids received for furnishing cement are too high there is often great temptation, in large works, to build a plant and manufacture the cement on the ground. Such efforts are always risky, however, as they call for the services of the most experienced men, who are hard to get at the salaries usually offered. The raw material to be used must be carefully analyzed in order to enable the proper proportions to be given to the ingredients. The burning also requires a very experienced man who knows just when the clinker has reached the proper stage. If the prices offered by the old standard cement companies are at all reasonable, it would be far better to accept them, rather than run the risk of turning out a poor article and having disintegration troubles develop maybe a year after the works are completed and paid for.

Reforms in the present State laws are certainly badly needed, and it is not at all clear how this can be gracefully done. The State decisions have all been in line with the old common law of England,

which is still in force in California. Feeble efforts are now being made to upset these old doctrines, but the progress made is very slow and unsatisfactory. **Mr. Le Conte.**

The good work done by the Department of Agriculture in studying the application of water to crops and in determining the average duty of water is certainly very commendable. Experience everywhere seems to show enormous waste of water at first; then, as the ground-water level rises, the need for irrigation becomes much less, and the consumption of water is very much reduced. In point of fact, there seems to be a close relation between the depth of the ground-water below the surface and the quantity of water needed for the crops.

The cost of reservoir capacity given by Mr. Mead, namely, $7 to $8 per acre-foot, is certainly very creditable, and speaks well for the reservoir sites selected. The suggestion made by the Secretary of Agriculture that no reservoir should be built by the Government until the State interested has first passed suitable laws, which would insure definite and final establishment of titles to water, is a good wholesome medicine, a dose of which the State of California is badly in need of.

David M. Duller, Jun. Am. Soc. C. E., Houston, Tex. (By letter.)—Mr. Mead seems to have presented a political rather than an engineering paper. As political conditions control the development somewhat, as to construction, it is of interest to study the subject, as he presents it, and to learn the circumstances governing the development of arid lands by irrigation. Mr. Mead merely mentions the fact that there are lands on the Gulf Coast which are irrigated. **Mr. Duller.**

The writer presents this discussion on irrigation in Southwestern Louisiana and Texas as supplementary to the broader subject.

The object of irrigating lands in Louisiana and Texas is for the production of rice. The area of "rice lands" is limited. Noting the fact that certain peculiar conditions must exist to assure the production of rice, Southwestern Louisiana and Southeastern Texas comprise the territory, in the United States, which, undoubtedly, is best fitted, physically and naturally, for the production of this crop. This territory is about 300 miles long and 25 miles wide, and comprises about 4 500 000 acres, known as the "Great Southern Rice Belt." After eliminating from this belt, the waste lands, such as swamps, marshes and timber strips, there is available for rice culture a territory not exceeding 2 500 000 acres. Rice will not grow without fresh water; and, of this territory, not more than one-half, or 1 200 000 acres, is provided with this necessity by the numerous rivers and bayous running through it and an artesian water supply beneath it, at a depth varying from 100 to 300 ft. This land may be described as being level prairie, with an average fall toward the

Mr. Duller. Gulf of 1.0 ft. per mile. Of this 1 200 000 acres, about 750 000 acres are developed for irrigation at present, of which it is estimated that one-half has been cultivated in 1904.

The writer's endeavor will be to present a description of the general methods, machinery and devices used in the irrigation of these lands with water from rivers and bayous.

There is no other production, or crop of the soil, irrigated in the same manner, or to the same extent, as regards the quantity of water required. It is not enough to have the soil moist; the water should cover the ground at least 0.25 ft. The flooding season continues from the time the rice is from 4 to 6 in. high, until it is matured, practically 90 days. During this period, it is necessary to furnish 2.2 ft. of water, to keep the required amount on the ground to provide for evaporation. Rice lands are farmed in the same manner and with machinery of the same class as those for the production of wheat.

For clearness and precision, this description will start with the water at the source of supply and follow it through the plant and the canal to the fields where it is used. Before commencing this, however, it must be stated that irrigation, by the present methods, has been undertaken and accomplished only within the last twelve years. Prior to that time, to a certain extent, rice was raised and watered by rainfall, which was stored in reservoirs and fields which were "leveed" to hold a sufficient supply for the flooding of the lands. This method was, and is, termed "Providence" irrigation, and is declared to be in all cases, sooner or later, an entire failure, on account of the uncertainty of Providence, and has been abandoned on that account.

The first question to be determined, in all cases, is the acreage to be irrigated by the proposed works, and with this the engineer must begin his calculations for the system. The area to be irrigated must depend on, and be determined by, the water supply in the river or bayou. An estimate of the portion of the river flow available for the particular plant will establish the principal feature of the proposition. Great mistakes have often been made by overrating the local water supply. It has been found by experience that 8 gal. per min. is sufficient for each acre irrigated, exclusive of rainfall during the flooding season. Thus the capacity of the plant in gallons should be eight times the number of acres irrigated, *viz.*, to irrigate 10 000 acres, the capacity should be 80 000 gal. per min.

The next question is the elevation to which the water must be lifted, in order to distribute it over the highest lands of the territory, and, at the same time, include a quantity sufficient to irrigate or flood the lands along the line of the canal. This elevation is from 10 to 65 ft., or an average of about 25 ft., for the plants now

in operation. Having the capacity and the elevation to which the water is to be raised, the details to be decided are the number of pumps, boilers and engines. Manufacturers of machinery are generally asked to submit bids for the machinery and guarantee the results demanded by the canal company, the machinery to stand a special test at the time of completing the erection, prior to acceptance by the company. Mr. Duller.

The pumps most commonly used are the Morris, Lawrence and Ivens' Centrifugal, and the Root and Connersville Blower. The writer would recommend in all cases that plants be erected in duplicate. For instance, for a plant with a capacity of 80 000 gal. per min., he would recommend that four pumps be used in two batteries, with a direct or rope-driven connection, of one engine with two pumps. In this manner, a part of the machinery can be repaired without disturbing other parts. An additional reason is that, at times during the flooding season, the whole capacity of the plant is not required to hold the supply of water in the fields, and a part of the plant can be operated singly.

The water is discharged from the pumps into a flume, in most instances, and from the flume into the canal proper. The design for a flume at this location on the plant can be the same as on the canal at the crossings of drainage, with variations suitable for the particular plant. A general flume design for the transmission of the water from the pumps to the canal cannot be used, owing to the varying physical condition of the banks of the river or bayou. Circumstances sometimes make it necessary to excavate an intake ditch from the river channel to suitable ground for the foundations of the plant.

The general requirements of levee construction are that a cross-section be determined, based on the materials to be incorporated in the levee. Levee construction is done generally with drag scrapers, and there is no doubt that this is the best method of placing earth in levees for canals. When wheelbarrow work is necessary, the levee is not as strong as it should be, having merely the weight of the loose materials as they are laid in the embankment. Considerable allowance must be made for settlement, generally 20% of the fill. With levees composed of certain materials, the effects, when water is run into the canal against new work, is sometimes disastrous. The uneven weights in the embankments, by the material on one side being dry and on the other side wet, cause them to slough. On the other hand, when the embankments are built by slip-work, the materials are always being tramped and settled in layers of very satisfactory thickness and cross-section by the teams. A detail, in the case of high embankments, would be that each layer should be plowed so that the next would have a good bond, and thus

Mr. Duller. insure water-tight joints and not leave a seam through which the water could find its way through the levee. In every case an allowable shrinkage is considered, according to the clays deposited in the embankment.

A general average height for canal embankments or levees is about 4 ft. Fig. 4, a cross-section of a canal, illustrates clearly the general construction of the embankments.

It is advantageous to construct a table of quantities for levee construction, as it saves considerable time to have the construction regular as to cross-section, and this is facilitated by a table of quantities, of the same character as those used in railroad work.

The graphical diagram, No. 26, in Coffin's "Graphical Solution of Hydraulic Problems," is of great service in making preliminary plans for canals.

CROSS-SECTION SHOWING GENERAL CANAL CONSTRUCTION.

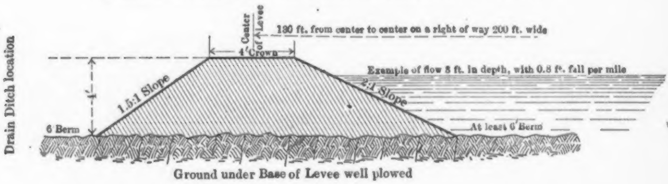

FIG. 4.

Fig. 5 is a general design for a flume crossing drainage. This plan is now used quite commonly, many expensive experiments having been made with cheaper designs. For narrow lateral canals, Fig. 6 will be as secure and serviceable a construction as the more expensive one shown in Fig. 5. Flumes have always been the "bugbear" of canal companies, on account of the expensive accidents which have occurred with them. The bulkhead, or connection between the woodwork and the earth, was sometimes washed out; or some weakness in the design and construction was overlooked, such as having a span too long for the floor joist, or the settlement of pile and trestle foundations. In the latter case, a slight springing downward under the load sometimes opened the construction so that the water was lost, and a week's delay for water in a dry season is a serious matter to a planter, who has his all in a crop dependent upon the water from the canal.

Until the last six years, companies depended largely on their own experiences and experiments; but they now see the necessity of having competent engineers at hand and show appreciation of their counsel and work.

In some instances, it is necessary to lower the grades of the canal on account of the profile of the line, and, in such cases, a check-gate is constructed to hold back the water. A satisfactory design, which is not expensive and is entirely secure, is shown in Fig. 7. Mr. Duller.

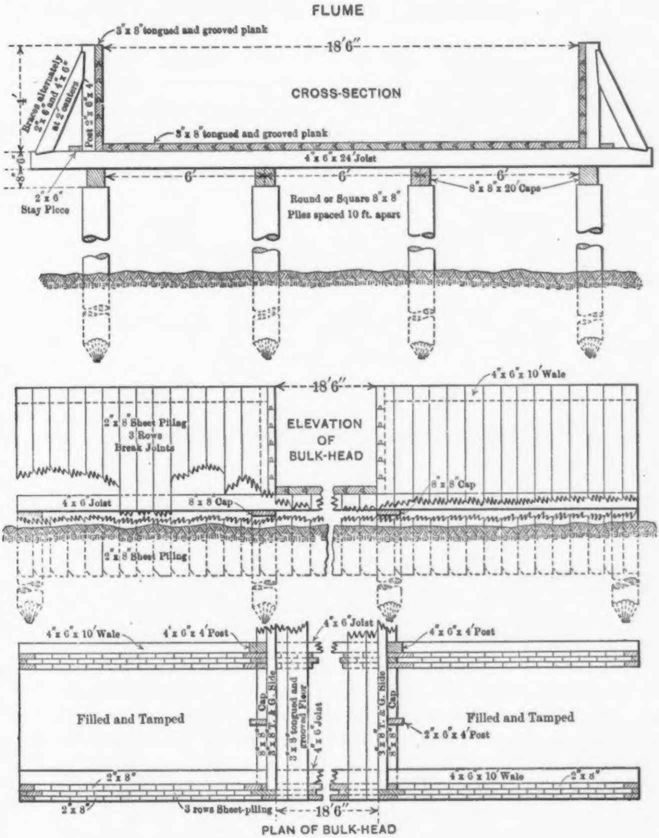

FIG. 5.

There are a few canals which do not require a portion of the water to be relifted, to serve the lands above the elevation of the flow line of the main plant, at the source of supply. This is necessary because it is too expensive, or is not feasible, to construct par-

Mr. Duller. ticular systems with established grades which will deliver water from the first elevation to irrigate the entire territory to be covered. A relift plant may be of the same design as the main plant, except that the lift required is generally very much lower. In some systems a third lift is required to serve the lands properly, and in such cases it is too expensive to operate under the present methods of management.

From the canals and laterals along and through the farms, the water is delivered to the fields through gates (Fig. 8) constructed of timber and of various design. The method of actual distribution of water from the canal to the fields and from field to field is not economically cared for and looked to by any canal company,

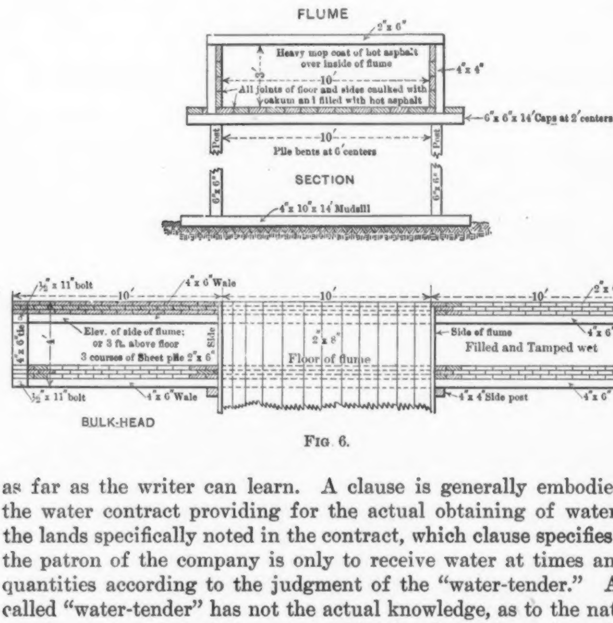

FIG. 6.

as far as the writer can learn. A clause is generally embodied in the water contract providing for the actual obtaining of water for the lands specifically noted in the contract, which clause specifies that the patron of the company is only to receive water at times and in quantities according to the judgment of the "water-tender." A so-called "water-tender" has not the actual knowledge, as to the natural requirements and need for water, which he should have, in order to protect the company from waste. To be sure, it is out of the question for an employee of an irrigation company to attend and mark the condition of all the field levees, and know that the patron is not letting the water through and out of his lands to waste. It will soon become a necessity to measure the water at the canal gate, so

Mr. Duller

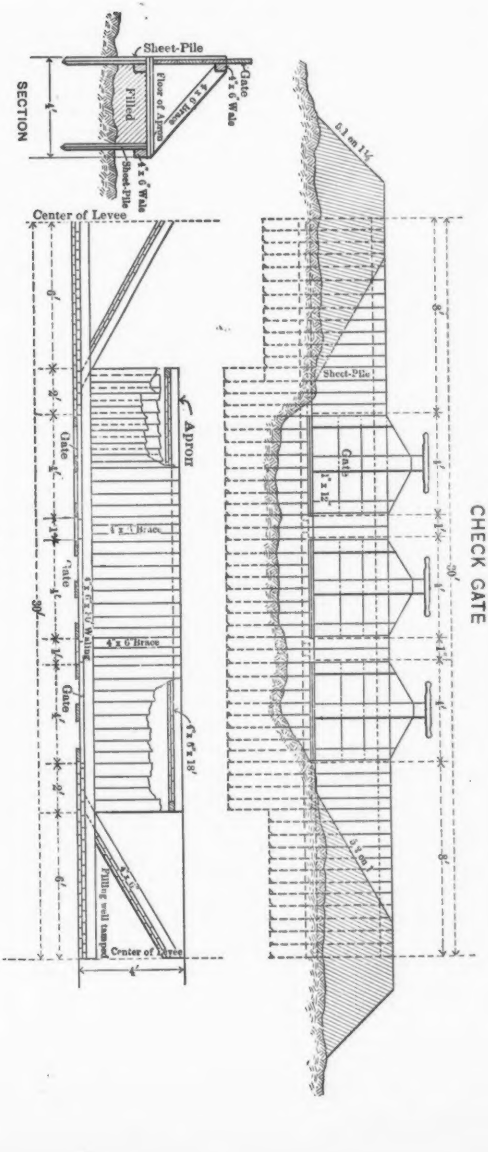

FIG. 7.

Mr. Duller.

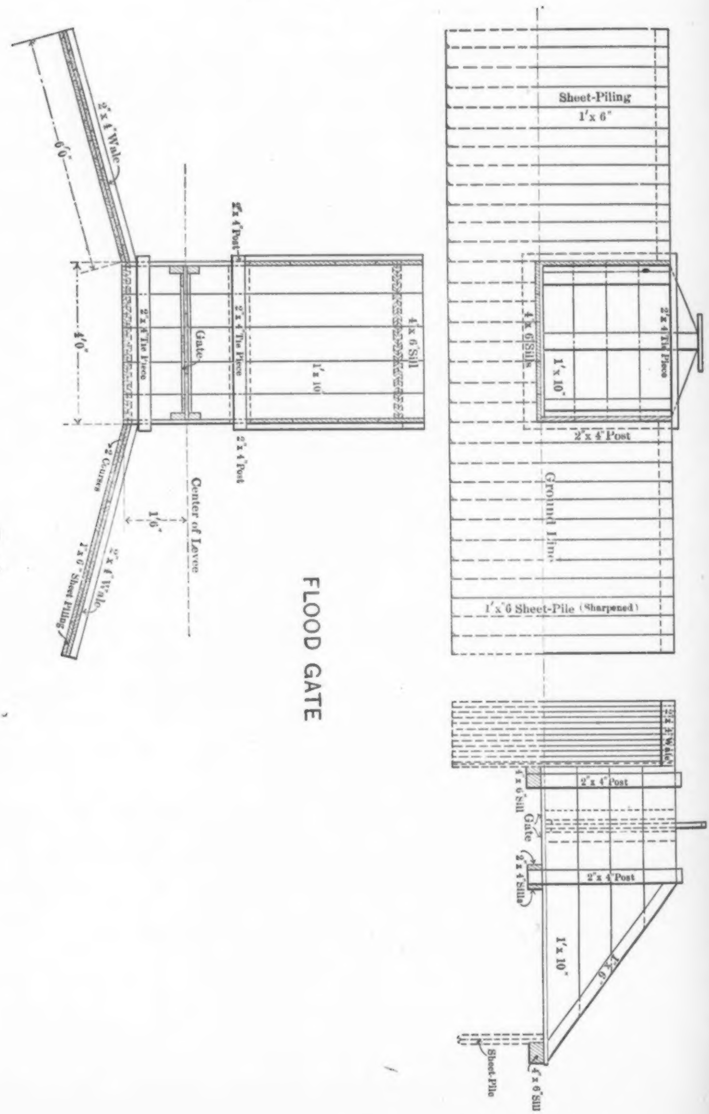

FIG. 8.

as to provide the required quantity in a regularly calculated time, for the number of acres actually being irrigated from the gate. Mr. Duller.

The field levees are low dikes, plowed and "pushed" to an elevation of about 1 ft., so that, being located on contours of 0.25 to 0.50 ft. difference in elevation, the water will be held at a depth sufficient to flood the land between the contour levees. They are "pushed" to the elevation necessary by a **V**-shaped machine made for that purpose by the farmer.

Canal companies furnish water to farmers of rice generally for the price of one-fifth of the entire crop produced by the lands irrigated by them; said fifth part to be separated from the whole at the threshing-machine. This amounts to an average of 2.2 sacks per acre, which, from year to year, is worth about $3 per bbl. A barrel of rice weighs 162 lb. and a sack weighs from 180 to 210 lb. One barrel of rice is required to sow three acres of land. It costs the farmer about $10 per acre to raise rice. An average crop is from 10 to 15 bbl. per acre. It costs from $10 to $12.50 per acre to construct irrigation systems which will irrigate rice lands economically.

Sir Hanbury Brown, K. C. M. G., M. Inst. C. E., Crawley Down, England. (By letter.)—There is much in the paper by J. E. de Meyier which suggests parallels in experience and practice between Java and Egypt. Two points only will be selected for remark. Sir H. Brown.

First, the reference to "the delicate relation between the engineer, head of the irrigation circle, and the resident," who is described as "the great center of the administration," recalls the early days of British control of the Irrigation Service in Egypt, when the Anglo-Indian Inspector of Irrigation was introduced as a "new wheel" into the machinery of administration, and held executive power in the Provinces independent of the Moudir or Governor of the Province, who had, till then, been lord of all within the limits of his charge. The native Chief Engineer of the Province had, until the creation of English inspectors of irrigation, been under the immediate orders of the Moudir and was his humble servant—practically if not theoretically. Henceforward he was to take his orders from an inspector who would see that they were obeyed, though it was, at the same time, still his duty to advise the Moudir in technical matters. The inspector was answerable to none but the Minister of Public Works, while the Moudir was answerable to the Minister of the Interior. So it came about that there existed two administrative chiefs in the Province, where, hitherto, the Moudir had reigned supreme. One of these powers resisted innovation and reform with the accumulated inertia of the Mohammedan East, and the other pushed his reforms with the persistent energy of his nature and with the relish of a new broom. Naturally, difficulties arose which sometimes developed into acute crises. The native chief engineers were

Sir H. Brown. embarrassed between their habits of subservience to the Moudir and their fears of the unknown limits of the new inspector's powers. A decree was issued defining the relations between Inspectors of Irrigation and Moudirs. It was not, however, the decree, but the tact, straightforwardness and honest purpose of the inspectors which finally decided what the relations between them and the Moudirs should be, and changed the discord into harmony.

The second point in the paper to which the writer would refer is the paragraph about "irrigation by turns." The same system, known as the rotation system, was introduced into Egypt for the same reason that it was adopted in Java. Egypt borrowed the system from India. Its severest application was made in the summer of 1900, when the scantiness of the available water supply, in comparison with the cultivated area, exceeded all experience. The problem was this: There was a certain area of land under cotton which had to be irrigated; there was a constantly diminishing supply with which to irrigate it, and no storage reservoir to counteract the diminution. So, unless somebody's crops were sacrificed, these two factors were fixed and unchangeable. A given discharge takes a definite time to irrigate a given area, and, as the discharge decreases, the time of the operation must increase, that is, in other words, the intervals between the waterings of any particular field must increase. It was found a convenient arrangement to divide each separate system of canals into three sections, *A, B* and *C*. Now, much of the irrigation was effected by pumps which, it was calculated, could complete the irrigation of all the crops depending on them in six days. So six days was accepted as the period of working for each section. If the water supply had been sufficient to irrigate the whole cropped area in eighteen days, each section would have taken water in turn for six days and have been prevented from taking it for twelve; that is, the interval between waterings for any particular field would have been eighteen days. But it was found that the supply was only sufficient at first to give one watering in twenty days, and, later on, in twenty-four days; and still later, at lowest supply, in twenty-eight days. To arrange for the twenty-eight days' rotation, it was necessary to rearrange the subdivision and split the systems into four sections, instead of three, which were called *D, E, F* and *G*, to avoid confusion with the threefold arrangement. The programmes of rotations were then made out on the following basis:

Sir H. Brown.

	One watering in 20 days.	One watering in 24 days.	
Section *A* works	6 days.	6 days.	*B* and *C* stop.
General stoppage	1 "	2 "	....
Section *B* works	6 "	6 "	*A* and *C* stop.
General stoppage	1 "	2 "	....
Section *C* works	6 "	6 "	*A* and *B* stop.
	20 days.	....	....
General stoppage	....	2 days.	....
	....	24 days.	....

	One watering in 28 days.	
Section *D* works	6 days.	*E*, *F* and *G* stop.
General stoppage	1 "	....
Section *E* works	6 "	*D*, *F* and *G* stop.
General stoppage	1 "	....
Section *F* works	6 "	*D*, *E* and *G* stop.
General stoppage	1 "	....
Section *G* works	6 "	*D*, *E* and *F* stop.
General stoppage	1 "	....
	28 days.	....

The general days' stoppages were intended to provide for the filling of the channels of the section whose turn to work came next, so that the water might reach the tail ends of the sections, and the pumps at the tails have as good a supply from the commencement of their six days' period as those higher up on the canals. These intermediate general stoppage days were also used to give water to those who had been badly supplied during their proper working period. It was also arranged that, if the tail reaches of any section did not get water in their proper turn, they should be given water with the section whose turn came next, as it would then be possible to get water to them, since all the pumps, or heads, above them on the same branch would be stopped. The intermediate days' general stoppage provided a reserve which could be utilised to prevent arrears accumulating to such an extent as to upset the published programmes and introduce confusion during the most critical period.

In the summer of 1900 the supply was so short that provision could not be made for rice irrigation, which crop, in comparison with the cotton crop, was of little importance in both extent and value. By such measures as described, the "duty of water" obtained was 700 cu. ft. per day per acre of crop, or 280 cu. ft. per day per acre of gross (taxed) area, assuming that two-fifths of the gross area was under cotton. This "duty" gives the rate of supply in the

Sir H. Brown. river at the main canal heads. But, in the summer of 1900, some of this crop suffered in yield from insufficiency of irrigation, so that the "duty" was duty imperfectly performed, and the inference drawn was that an allowance of 700 cu. ft. per day per acre was insufficient to obtain a full harvest.

The conclusions arrived at, after the experience of a succession of low summers, as to the best programme for rotations is thus stated in the Irrigation Report of Egypt for 1902:

"As a consequence of previous experience, it has been decided in 1903 to adopt the three-section arrangement of distribution, by which each section takes water in turn for a third of a full period which has been fixed at eighteen days; so that each section will get water for six days and be without it for twelve. For canals, however, from which rice is irrigated, two sections are adopted, each section working for four days and stopping for five. The day when neither section works comes after the working of the first section, and is utilised for filling the channels of the second section before water is drawn off from them. As the rice full-period is half of the cotton period, a cultivator may, if he likes, raise cotton or rice or both. Supposing he has an area of 200 feddans (acres) to put under crop, he can put it all under rice and irrigate it once in nine days; or he can put it all under cotton and irrigate 100 feddans during one turn and 100 feddans during the next, so that one watering in eighteen days is given to it all. Or he may put 100 feddans under rice and 100 under cotton. In this case he would irrigate all the rice and 50 feddans of cotton during one turn; and all the rice again and the other 50 feddans of cotton the next turn; so that, in every case, the rice would get a watering in nine days and the cotton in eighteen days. The cultivator is thus free to plant what he likes."

This programme contemplated assistance from the Assuan Reservoir. Without it, the period of eighteen days would have had to be increased to twenty-one or twenty-four days by inserting one or two days' general stoppage between each section's period of working, as was done in 1900.

With a period of nine days between waterings of rice and of eighteen days between waterings of cotton, and allowing 4⅓in. depth for each watering for cotton (inclusive of allowance for waste between canal head and field), the discharge required at the canal head was found to be 1 000 cu. ft. per acre of cotton crop and double that figure for rice. If the supply falls short of these allowances, there are only two ways of meeting the deficiency of supply, namely, either by lengthening the intervals between waterings, or by reducing the area of crop to be watered. The former is really the only practicable alternative.

There is one point in which the Egyptian practice differs from that of Demak in Java, which may be noted. Mr. de Meyier states

Sir H. Brown.

that a native who does not begin the tillage of his land at the time officially decreed incurs punishment. In Egypt the cultivator is not punished for sins of omission, but he is called to account if he takes water out of his authorised turn. If he neglects to take it when he is authorised to do so and the water is provided, that is an affair that concerns himself, and his punishment is the injury his crop suffers through his own neglect of it.

It is gratifying to find two such eminent authorities on irrigation as Sir Thomas Higham and General Rundall taking part in the discussion.

Sir Thomas Higham argues that:

"As the payment of the land tax in Egypt conveys a right to a water supply, and the tax is entirely remitted in the event of a failure of the supply, the rate of this tax * * * may be fairly regarded as the charge for irrigation."

The writer does not think that this is a logical conclusion, as the land tax is the principal tax producing the revenue which pays for not only the irrigation outlay of the State, but also for the expenditure necessary to provide for public security, to maintain an army, and, in short, to meet the cost of governing the country as a civilised state. There is no separate property or income tax in Egypt. Therefore the attempt to compare the cost of irrigation per unit of area in Egypt and India is somewhat hopeless.

The proportion of lift to flow irrigation in Egypt is not accurately known. All basin irrigation is flow irrigation. About three-fifths of the Delta has flow irrigation, and two-fifths lift in summer. The whole of Upper and Middle Egypt is flow, with the exception of about 40 000 acres. Taking the whole of Egypt, five-eighths gets flow irrigation in summer and three-eighths lift. But during flood almost the whole of Egypt gets flow irrigation. But whether the irrigation is flow or lift is a matter of less importance than whether the land gets a perennial supply of water or a flood-season supply only. The land tax, under the new assessment, takes account of all favourable and unfavourable conditions. For, as stated in the writer's paper, the land tax is based on the renting value of the land. And the renting value is high or low according as the algebraic sum of the conditions affecting it is favourable or unfavourable. Such conditions are: Nature of soil; irrigation and drainage arrangements; means of transport; distance of market; and everything affecting the production and disposal of the crops raised on the land. No fairer basis for the determination of the rate of the land tax than the renting value of the land could have been made use of. But whatever the disadvantage may be, such a method of arriving at the land tax does not lend itself to a separation of the charge for water.

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Sir Thomas Higham quotes Sir William Willcocks as stating that two-thirds of the cultivated land in Egypt are rented at a mean value of £5, and the balance at a mean value of £1 per acre per annum. The £5 as stated by Sir William Willcocks must be a misprint for £3. The correct figures are: 4 000 000 acres rented at £3, and 2 000 000 at £1; the total amount of the land tax is 4½ million pounds, or a little less than one-third of the rental.

General Rundall refers to the most important question of water-carriage. There seems reason to think that the Government of India is awaking to the necessity of a more liberal policy in this respect. The tolls have been reduced on some of the navigable routes, and measures are being considered for improving the great navigable waterways, which, in Bengal at any rate, carry such a large proportion of the trade of the country. General Rundall is evidently not aware that a railway has been constructed through the heart of the tract irrigated by the great Chenab Canal in the Punjab. He thinks that all great irrigation canals should be navigable in order to afford facilities for the export of surplus products. Experience on one of the great canals in Bengal has not supported this theory. The canals, although navigable, are but very little used as such. It must be remembered that an irrigation canal, when it is carrying its full volume of water, has, in most cases, a velocity which is a most serious impediment to traffic which is proceeding up stream, and, sometimes, a danger to that going down stream. Further, irrigation canals, which, primarily, are designed to meet agricultural needs, are rarely aligned to follow trade lines. Consequently, trade will not use them. However, the importance of water carriage is great, and General Rundall does good service in bringing the matter forward. What is needed is not the construction of isolated canals, navigable from nowhere in particular to nowhere else in particular, as is largely the case at present, but, as he says, navigable channels along well-travelled trade routes.

General Rundall is mistaken in thinking there is any error in the figure given in Table 1. The canals in Bengal may command 2 000 000 acres, but they could not irrigate half that area. The figure given in the paper refers, it should be remembered, to food grains, and the total area irrigated by the canals includes crops which are not food grains.

Mr. Elliot seems to think that there was room in the writer's paper for reference to engineers who proposed the works carried out. The "Introduction" to the paper points out that "as the subject of 'Irrigation' is a large one, and 'limits have been assigned to this paper,' references are given in foot notes to the various publications in which fuller information may be found." The

writer would refer him to the Appendix to the paper, "The Delta Barrage" will show that the writer was aware of the connection of Sir John Fowler, and other engineers, with the Barrage. The history of the study of the storage on the Nile and of the Wady Rayan will be found in several of the works given in the Appendix. The limits assigned to the paper were so restricted that the luxury of naming those who were connected with irrigation in Egypt, both before and after Mr. Elliot was there, had to be foregone. Sir H. Brown.

The writer questions the accuracy of the statement that a better site for the reservoir could have been obtained at Wady Halfa, but he has never been to "the then terminus of the Halfa and Khartoum Railway."

Mr. Elliot is right in thinking little of a reservoir that is only capable of holding 2 000 000 or 3 000 000 cu. m. above draw-off level. The "millions" of the paper was due to an error in the manuscript, the word should have been milliards. The calculations take account of the evaporation; and the 2 000 million or 3 000 million cu. m. is what the Wady Rayan is calculated as being able to supply; not merely capable of holding.

Full information about the Assiout and Zifta Barrages is to be found in the *Minutes of the Proceedings* of the Institution of Civil Engineers for 1904.

The Victoria Nyanza figures relating to evaporation have not as yet been verified. As regards the lowering of the lake level, the Germans might object, as well as the Traffic Manager of the Uganda Railway. The proposals made by Sir William Garstin in his late report on the Upper Nile would interest Mr. Elliot. Sir William Willcocks, some years ago, suggested the willow for training in the "Sadd" region. Sir William Garstin has lately suggested the "ambash" for the same purpose. But all these matters, referred to by Mr. Elliot, cannot be dealt with in a paper of a fixed length, or in the discussion on it, without exceeding reasonable limits.

Professor Chatterton is quite right in attaching importance to wells. There was no intention to depreciate them. Regarded from a purely agricultural point of view, they may, no doubt, be classed as irrigation works. They water more than 25% of the whole irrigated area of India. But in a paper mainly written from the point of view of the engineer, wells hardly fall under the title of irrigation works.

With reference to Mr. Fuller's remarks about the temperature of the water in wells and in open channels, it is the fact that, in India, there is, in the cold weather, a great difference between the two. The cultivators of opium in Behar refused to take canal water for their crop, on several occasions, on account of its coldness as compared with well water. In the hot weather, however, the differ-

Sir H. Brown. ence is the other way and in favour of the canal water. The warmer water is certainly better for the crop. But well water contains none of the fertilising silt which is so much valued by the cultivators, and which they obtain, at certain times of the year, from canal water.

Mr. Salvador. PAUL LEVY SALVADOR, ESQ., Paris, France. (By letter.)*— Mr. Mead's interesting paper shows how difficult it is, in the United States, to insure a fair distribution of river water for irrigating purposes to those entitled to its use, especially during periods of very low water. The author mentions, particularly, the case of the Arkansas River.

In France, the same difficulty was experienced on the Durance River, a tributary of the Rhone, having a length of 300 km. and draining a water-shed of 14 814 km., descending from the high Alps.

Being fed principally by ice and snow, the extreme low water occurs in winter; the discharge begins to increase toward April, when the snow begins to thaw, and it gradually increases until the end of June. At that time, there are heavy rains which bring on important floods, but these are of short duration. On the contrary, in summer, the rains are very infrequent and the temperature very high; the discharge begins then to decrease until September when the autumnal rains begin. When cold weather sets in, the discharge decreases again and reaches its minimum toward the end of February.

The regimen of the Durance is torrential; in the down-stream part of the river, the floods reach at times more than 3 600 cu. m. per sec., while at extreme low water, the discharge has been as low as 25 cu. m. per sec. In the last 88 km. of its course, the river crosses the rich plain of Provence, which owes its fertility entirely to summer irrigations; along this course, the river feeds twenty irrigating canals, having a total legal allowance of 88.5 cu. m. per sec.

As stated in the paper, the irrigating season lasts six months (from April 1st to October 1st), and although this season coincides with the season when the waters of the Durance reach their highest level, it has happened several times that the discharge of the river, in its down-stream portion, has fallen much below the figure necessary to permit of a simultaneous feeding of all the canals; in April, 1896, particularly, the discharge was but 48 cu. m. per sec., or 40 cu. m. less than the required amount.

According to the French legal code, the oldest concessions have the preference and stand in order of seniority. As some irrigating ditches fed by the Durance are very old (the three oldest have titles of concession dating, respectively, from 1428, 1554 and 1754, while

* Translated from the French by Paul A. Seurot, M. Am. Soc. C. E.

others were only established during the eighteenth and the nineteenth centuries), the State might have ordered, as far as necessary, the closing of the various canals, beginning with the most recent ones. This extreme measure was not applied, however, owing to the damage it might have caused to the consumers of the water of these irrigating ditches, but as several of the consumers were suspected of taking more than their legal quota of water, it was decided to adopt another solution whereby the disposable volume of water could be distributed between the several concessions in proportion to the legal allowance of each one. To this effect a regular section was chosen on each irrigating ditch as near as possible to the intake, and at this place a graduated gauge was located, as well as an apparatus recording automatically the variations of the water level. After some experiments a table and diagram of the discharges corresponding to the various heights of the gauge were gotten up, which permitted one to compute the discharge, at any time, by a simple reading of the gauge. Mr. Salvador.

At its source, the Durance runs through a narrow gorge between two ranges of high hills and flows in a single channel; observations are taken regularly in that section in order to gauge the flow and discharge of the river. Since then it has been easy to fix the proportion by which each intake should be decreased when the discharge falls below 88.5 cu. m. per sec. Four inspectors were appointed by the State to see that each consumer received only the quantity to which he was legally entitled. And even during the lowest stages of the water, no infraction against this ordinance was reported, although in April, 1896, it was necessary to reduce to 0.060 of the normal quota, the volume allotted to each consumer.

These measures are, after all, but mere makeshifts, or rather palliative measures, and, for some years past, engineers have studied the possibility of building, in the region of the Upper Durance, storage reservoirs for the flood waters, which could be used to increase the discharge of the river during periods of scarcity. The problem is here particularly difficult, because the Durance, in times of floods, moves and carries great volumes of silt and gravel. It had been thought that a great dam built across the Upper Durance would be sufficient; but this idea had to be abandoned for fear that the reservoir would be rapidly filled up with gravel. It is proposed now to build several smaller reservoirs in the upper part of tributaries descending from wooded slopes and carrying less gravel; nevertheless special measures must be taken to insure their flow by energetic flushing effected alternately on all the reservoirs.

Before closing, the writer would say a few words regarding the difficulties attending the feeding of the irrigating ditches with the water of the Durance during the various stages of the river.

Mr. Salvador. While during the flood seasons, the main channel of the river is more than 1 km. wide, at low water, it is divided into several small branches which run sinuously through the gravelly bottom; after each flood, this gravel is moved and carried from place to place, changing the location of the small streams. This condition has been partly improved by the erection of submersible dikes which fix the channel within certain limits during the ordinary stage. The intakes are located, as far as possible, on the concave shores near points toward which the current runs, or toward which it is directed by movable dams made of fascines and boulders which are carried away by the floods.

At some points, the concave shore is limited by rocks jutting out, the base of which is always under water. It is at one of these points that in 1885, at the time of its reconstruction, the intake of the irrigating canal of Châteaurenard was located, which canal receives an allowance of 3 000 liters per sec. At its source, the canal passes through the rock in tunnel, and the section where the water is measured and gauged is located at the exit from the tunnel. As is shown in Plate VIII, the intake consists of four iron gates; the apparatus controlling the movements of these gates is located on a platform erected 1 m. above the highest known water level.

When the writer mentioned the use of rams for raising water from streams for irrigation purposes, he took into consideration only the raising of small quantities of water to an ordinary height.

In France only the riparian proprietors have the right to use the river for irrigation purposes. The division of property into small holdings has resulted in a great many small enterprises, and those interested hardly ever combine to erect one large plant which would certainly diminish the individual expense of irrigation.

The ram actually used differs only slightly from the original Montgolfier pump in details of construction, which have been introduced only in order to eliminate the hurtful effects of shocks.

The modifications in question have resulted in an improvement in the efficiency of the apparatus, which reaches from 70 to 75% as long as the ratio between the elevation and fall is not greater than 5 or 6 and even reaches 55 to 60% when this ratio becomes 20 or 30. The writer can cite, as an example of the use of the ram for irrigation purposes, the case of the apparatus installed some ten years ago in the Department Corrèze, which uses 3 300 liters per minute; it works under a fall of 6 m., and raises 550 liters per minute to a height of 25 m. The efficiency, therefore, is greater than 70 per cent.

When it is necessary to raise quantities of water to a great height, the pumps which have been described in the writer's paper are used.

INTAKE OF IRRIGATION CANAL OF CHATEAURENARD.

J. E. DE MEYIER, Esq., The Hague, The Netherlands. (By letter.) Mr. de Meyier. The system in Demak, described as "irrigation by turns," is not exactly the same as that known as the rotation system in Egypt, and the following special case may be given as an example. Suppose we have a certain extent of ground where a quick-growing kind of rice must be cultivated. That rice on that ground, which is very heavy clay, requires two weeks for plowing under a large supply of water. The watering can be alternate or by rotation, but the volume required corresponds to a continuous flow of 20 cu. ft. per sec. for every 1 000 acres. When the fields are plowed, the rice is not sown directly, but the seed is put in little nursery-fields, and afterward the grown seedlings are transplanted to the larger area. In this way, for 1 000 acres of rice-fields, only some 60 to 100 acres of nursery-fields are necessary during 5 weeks or more. In these 5 weeks, only a full supply for these fields, and a very small quantity for the further preparing of fields which have not yet been planted, are required. After transplanting the seedlings to the larger area, the water supply is gradually augmented for a week; it is maintained as a full continuous supply for three weeks, and afterward, toward the ripening, gradually diminished.

Placing the total area at 10 000 acres, and supposing that all the labor on all the fields took place during the same periods, in the 19 weeks required for the growing of the crop there would be necessary the number of cubic feet per second, which are inserted in the second column of Table 7. In that case, during the first 2 weeks, 200 cu. ft. per sec. would be necessary, and from the ninth to the eleventh week, 120 cu. ft. per sec. Now, it is supposed that the river never gives a supply greater than 95 cu. ft. per sec., but that water is available for a longer time than nineteen weeks, although in lesser volume, for instance, during twenty-five weeks. In that case, the area may be divided into five sections of 2 000 acres each. In the first 2 weeks only two of these sections get water for plowing, and the others must wait. This may be of great value, because cattle are not available to begin the plowing everywhere at the same time. If the water is sufficient, and the cattle are not available, perhaps, in the first 2 weeks, only one section of 2 000 acres can begin. The combinations, of course, are unlimited, but we may take the example, shown in Table 7, in which in the first 2 weeks Sections I and II begin, in the following 2 weeks, Sections III and IV, and, in the fifth week, Section V begins. After the seventh and ninth weeks, Sections I, II, III, and IV are ready for transplanting, but because it is the time when all sections want the full supply of 24 cu. ft. per sec., the transplanting of Section IV is retarded a week and that of Section V for two weeks, a difference that does not seem to affect seriously the value of the seedlings. In that way, the water

Mr. de Meyier. supply necessary for all the sections combined, as inserted in Column 8, is never more than 93 to 94 cu. ft. per sec. As the crop of Section V is perhaps more likely to require rain and the planting of older seedlings, the order of rotation is inverted in the following year, and this section takes the place of the former first section, etc.

TABLE 7.

Number of weeks.	SUPPLY IN CUBIC FEET PER SECOND FOR.						Aggregate supply required by section-division.
	The whole area of 10 000 acres at once.	The area divided into five sections of 2 000 acres each. Number of section.					
		I	II	III	IV	V	
1	200	40	40	....	....	....	80
2	200	40	40	....	....	....	80
3	25	5	5	40	40	....	90
4	25	5	5	40	40	....	90
5	25	5	5	5	5	40	60
6	25	5	5	5	5	40	60
7	25	5	5	5	5	5	25
8	80	16	16	5	5	5	47
9	120	24	24	5	5	5	63
10	120	24	24	16	5	5	74
11	120	24	24	24	16	5	93
12	100	20	20	24	24	5	93
13	100	20	20	24	24	5	93
14	75	15	15	20	24	16	90
15	75	15	15	20	20	24	94
16	50	10	10	15	20	24	79
17	50	10	10	15	15	24	74
18	25	5	5	10	15	20	55
19	25	5	5	10	10	20	50
20	....	....	....	5	10	15	30
21	....	....	....	5	5	15	25
22	....	....	....	....	5	10	15
23	....	....	....	....	....	10	10
24	....	....	....	....	....	5	5
25	....	....	....	....	....	5	5

It is clear that by dividing the area into six sections and by extending the time between the beginning of the first and the reaping of the last crop, a still smaller maximum for the whole area can be obtained, but that limits are fixed by the duration of the rainy season and by the time necessary for growing the crop, which in this case is 19 weeks, in others 26 weeks or more.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

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TRANSACTIONS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

MARINE ENGINEERING.

Congress Paper No. 36.

By W. F. Durand, M. Am. Soc. M. E.,
Stanford University, Cal., U. S. A.

Congress Paper No. 37.

IN FRANCE.

By V. Daymard, Ancien Ingénieur de la Marine,
Paris, France.

AND

R. Lelong, Ingénieur Principal de la Marine,
Paris, France.

Discussion of the Subject by

W. Carlile Wallace, New York City, U. S. A.
Sir William H. White, London, England.
Leslie S. Robertson, London, England.

Note.—Figures and Tables in the text are numbered consecutively through the papers and discussion on each subject.

TRANSACTIONS

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MARINE ENGINEERING.

By W. F. Durand, M. Am. Soc. M. E.

An examination of the two large volumes constituting the Report of the *Proceedings* of the Marine Section of the International Engineering Congress, held in Chicago at the Columbian Exposition of 1893, will serve to indicate, in a comprehensive manner, the status of the general art of marine construction at that period. An attempt will be made in this paper to indicate in briefer, and necessarily much more condensed, form the chief lines along which progress in marine engineering has moved since that time.

Fuel and Combustion.

The propulsion of a ship, in common with all other engineering operations, requires the expenditure of energy, and the activities of the marine engineer, therefore, have two main relations: (1) with the source of energy and its liberation or manifestation; (2) with the means best available for its transformation into the mechanical work of ship propulsion.

Thus far, heat energy alone has appeared as a practicable primary form, and the question of a fuel or a source of heat energy naturally presents itself as the first question demanding consideration.

Coal and fuel oil, as the two representative sources of carbon and hydrocarbon compounds, still hold the field, with practically no competition for marine-power purposes.

Regarding coal, its status as a fuel has remained without substantial change during the period under consideration. Some minor improvements have been made in the manufacture of briquettes, and also some advance in the methods of thus utilizing varieties or forms of coal not readily available under ordinary conditions. From the broad perspective view, however, coal has remained as the standard marine fuel, and with only such relative displacement as may have resulted from the somewhat varying use of fuel oil.

Regarding means for handling coal from the bunkers to the furnace, but little progress can be noted. A few installations of mechanical stokers have been attempted in order to parallel, if possible, the satisfactory service which such means of firing have given in stationary boiler and power-house equipment.

Perhaps the most notable examples have been furnished by trial installations on Great Lakes steamers, one of which has been reported on by a board of naval engineers after observations during an extended trip.* On the whole, the results of these attempts do not seem to have been entirely satisfactory, and the conditions prevailing on shipboard and in stationary boiler plants seem to differ to such an extent as to preclude the satisfactory use for marine service of stokers which may give good service with stationary boilers. Further, although efforts have been made to develop a satisfactory marine type of mechanical stoker, they have not met with encouraging success, and at present the mechanical stoker cannot be said to have gained a foothold in the standard marine practice of the day. This fact is the more surprising in view of the extent to which, in all branches of engineering, mechanical processes are displacing hand methods, and in view of the manifest advantages in the saving of hand labor as well as in the possibilities of utilizing cheaper grades of fuel. The mechanical handling of coal from the bunker to the furnace seems to be a yet outlying field for the conquest of the engineer and inventor, and it would seem strange if coming years should not bring with them some solution of this problem.

Regarding means for the combustion of coal, the experience of

* *Journal*, Society of Naval Engineers. Vol. XIII, p. 895.

the past decade has fully confirmed and established the use of hot draft where large output, without sacrifice of efficiency, is desired. The means now in use for forcing combustion are substantially the same as those in vogue in the early part of the decade, and may be classified as follows:

1.—Closed fire-room, involving the use of pressure blowers delivering air to the fire-room, the air pressure in which is thus maintained at an excess over that in the furnaces;

2.—Closed ash-pit and furnace, involving the use of pressure blowers delivering air under excess pressure through an air heater to the ash-pits and over the grates, as the needs of combustion may require;

3.—Induced draft, involving the use of exhaust or suction fans in the uptakes, and producing a defect of pressure in the uptakes, tubes and furnaces in consequence of which air enters through an air heater from the open fire-room under a head represented by such defect of pressure.

The closed fire-room system is not readily adaptable to the preheating of air, and, therefore, is but rarely used, except as an emergency provision, or on naval vessels where structural arrangements may render difficult the installation of the other systems. The closed furnace front, with excess of pressure and preheated air, as represented by the Howden system and its variants, and the induced system with exhaust fans in the uptakes and air preheated before entering the furnace, as represented by the Ellis and Eaves system, are both, however, firmly established in the engineering practice of the day, and each system is represented by a large and increasing number of successful examples.

The induced system is necessarily the bulkier and heavier of the two, and is installed usually at a somewhat increased cost, as compared with the Howden type. Notwithstanding these disadvantages, its operation, on the whole, seems to be more satisfactory in leaving the fire-room open, in admitting of a ready change to natural draft if desired, and in providing the operating conditions of an intensified draft for the boiler. Due to these general causes, the preference, as exhibited in present-day practice, seems, on the whole, to lie with the induced system. Both systems are so well known to the engineer-

ing public that no detailed description is necessary, and it will be sufficient, for present purposes, to give to the matter this passing notice, with reference again to the definitely established status which the principal of hot, mechanical draft has attained in the standard practice of the present day.

Undoubtedly, the chief line of progress relating to fuel during the past ten years has had relation to the improvements made in the practical methods of handling and burning fuel oil under the conditions which prevail in marine practice, and to this topic attention will now be given.

The *Proceedings* of the Marine Section of the Engineering Congress, held in Chicago in 1893, contain a most comprehensive paper by Colonel N. Soliani on the subject of oil fuel for marine purposes, and reference to this will serve admirably to show the attitude at that time in regard to its availability as a marine fuel, as well as to indicate the general extent to which its use has become definitely demonstrated as practicable, from the engineering and economic viewpoints. Since that time new sources of oil supply have been discovered and exploited, notably in Texas, California and Borneo, and there has been a general readjustment and gradual change in the distribution of oil and its relative availability, from the geographical viewpoint. These changes have also been paralleled by corresponding fluctuations in price, relative to coal, on the whole, downward rather than upward, and having in view the decade as a whole. These changes have resulted, in general, in a marked increase in the use of fuel oil for marine service, and especially within the past three or four years, a period which has brought more progress in this direction than perhaps any ten or twenty previous years.

No new fundamental principles have come into view bearing on the economic use or availability of fuel oil for marine purposes, and the practical improvements which have been made have been an expression of the better understanding and realization of general principles well known from the earliest days of its use.

Speaking broadly, the general conditions for efficient and rapid combustion of oil fuel are simple, and may be stated as follows:

1.—The introduction of the fuel into the furnace as a vapor, or in the most finely divided state possible, in order that its

passage into a vapor may be as nearly instantaneous as possible;

2.—The intimate mingling of the vapor thus formed with air sufficient for complete combustion;

3.—The production of the vapor at the highest practicable temperature, in order that, at the point of ignition, the minimum heat may be taken from the furnace for the elevation of the vapor to the ignition temperature;

4.—Suitable volumes in the furnace and combustion chamber, in order that the combustion may be completed before the gases enter the tubes.

Modern installations for the burning of fuel oil comprise the following main features, the relation of which to the general problem may be judged by reference to the preceding principles:

1.—Settling tanks for allowing the water, which is often found in small quantity in the oil, to separate and settle to the bottom, whence it may be drawn off. In many cases such tanks are provided in duplicate, and filled alternately from the main tanks, and thus the oil in one tank will be clearing of water while the other cleared tank is furnishing the oil for current demand.

The presence of water at the burners may give rise to trouble by interrupting the supply and putting out the flame, after which oil will continue to flow in and vaporize, with the danger of explosion.

2.—Means of heating the oil to insure fluidity at the burners, to facilitate separation of the water and to further the rapid transformation of the spray into the condition of vapor. Such heating is usually provided by coils carrying exhaust steam or hot water, preferably at the temperature of 150 to 180°, as it is found that a higher temperature will tend to produce a deposit of carbon on the oil side of the coils.

3.—Oil-service pumps, in accordance with the details of the system, and comprising, in general, means for handling the oil from the storage tanks to the settling and preheating tanks, and from these to the burners. In some cases the settling and heating tanks may be combined in one, while in others the heating is effected in a closed heater through which the oil is forced under pressure on its way from the burner-service pumps to the burners. Strainers

should also be provided between the pump and the burners in order to remove any impurities which would tend to clog the latter; and it may be recommended that such strainers should be installed in pairs in a double-branch pipe in each lead, so that in case of clogging the oil can be shut off from either strainer, which may then be removed and cleared without interrupting the normal supply of oil to the burners.

4.—Means for atomizing or vaporizing the oil and introducing it into the furnace with sufficient air for combustion. This item includes the burner as one of the distinctive features of the various so-called "systems" of liquid-fuel combustion.

It is understood that, ultimately, the oil must burn as a vapor, and the chief problem, therefore, has relation to the production of such vapor, and its proper mixture with the necessary air under the best conditions for economic combustion.

It is only within relatively recent years that the fundamental importance of minute pulverization has been fully realized, and, with this need clearly understood, progress in mechanical means for fulfilling such condition has been rapid. In many of the earlier attempts to use oil fuel, the oil was sprayed into the furnace by some form of injector, and only imperfectly atomized by such means. Under these conditions combustion was dependent largely on a bed of incandescent material, such as fire-brick, and such provision has formed an essential feature of many systems of oil-fuel combustion. It may be said, in brief, that the burner will, in general, be more efficient as it more completely atomizes the oil, and thus prepares it for rapid transformation into vapor within the furnace; and, furthermore, as this condition is more nearly realized, there will be a corresponding decrease in the need of an incandescent body of brickwork to maintain the conditions for perfect combustion.

In a general way, the methods used for atomizing the oil have tended to fall into two main groups: those which introduce the liquid as a fine spray atomized mechanically, or by steam, or compressed air, or some combination of these agencies; and those which first vaporize the oil in an external chamber or passage, and introduce it to the furnace as a vapor. In both cases it is presumed that the substance burns as a vapor, and the real difference in the systems consists in the introduction, in the one case, of a fine liquid

spray, which must almost instantaneously flash into vapor and then ignite, while in the other the condition of vapor is more completely realized before the oil reaches the furnace.

For realizing these conditions, three agencies may be mentioned, operating, briefly, as follows:

a.—High-Pressure Jet and Low-Pressure Air.—In this case the oil, under a considerable pressure, as, for example, from 20 to 30 lb. per sq. in., escapes from a small orifice and is spurted against some form of conical or helicoidal surface, or series of vanes, thus producing mechanically a spray of oil. This is followed by air under moderate blast pressure, for example 10 to 15 oz., and in sufficient quantity to answer all or nearly all demands for complete combustion.

In this system, therefore, all or nearly all the air required for combustion is handled under moderate blast pressure, and its chief function is undoubtedly the more or less complete vaporization of the jet after mechanical pulverization and before it reaches the point of ignition.

b.—Low-Pressure Jet and High-Pressure Air.—In this system the oil may flow by gravity or under very low pressure to the nozzles, where it is caught by a jet of high-pressure air, and more or less completely pulverized and swept on into the furnace. Not all the air needed for combustion is thus introduced, and an auxiliary supply must be provided in such manner as will insure a proper mingling with the spray, and the realization of the conditions needed for complete combustion.

c.—Low-Pressure Jet and High-Pressure Steam.—In this system the mechanical arrangements are similar to those of the preceding, but steam instead of air is used as the pulverizing agent, and all air needed for combustion must be supplied additionally.

There is, however, no absolute line of demarcation between these various systems as regards pressures used, and varying proportions of oil pressure and air blast or steam pressure have been successfully utilized.

As between air and steam for the atomizing agent, experience seems to indicate that the best economic results may be realized by the use of preheated air. This requires the installation of an air compressor or pressure fan as an item of auxiliary machinery, and

since such fan or compressor may break down, provision has been made frequently for the temporary use of steam under emergency cases. On the other hand, the use of steam is a most serious tax on the fresh-water supply, and necessitates the provision of extra evaporator or fresh-water storage capacity, in order to avoid the use of salt feed in the boilers. With the use of steam, it is believed that better economic results may be attained by superheating before admission to the burners, thus atomizing at a higher temperature than by the use of saturated steam.

In all cases, and in accordance with the principles noted previously, the use of air heated before admission to the furnace or admixture with the vapor has been shown to be favorable to efficiency. This is a feature of the greatest importance, from the economic viewpoint, and no small part of the recent advance in efficiency of operation is due to the better realization and fulfillment of this condition.

d.—The Furnace Arrangements.—In many cases these have included fire-brick on the grates, or a more or less complete fire-brick lining for the furnace, both for the protection of the steel plates and to serve as a reservoir of heat, as previously noted. In other cases, and especially where the oil is vaporized before introduction into the furnace, the brickwork has been discarded without serious results, provided the furnace is of sufficient size to permit of the completion of the combustion before the flame impinges on the metal surfaces. The question of the safety of the plates seems to turn largely on the provision of a volume and length sufficient to fulfill the condition just stated, and with a satisfactory fulfillment of this condition no trouble seems to be encountered with the structure of the furnace and boiler. Otherwise, rivet heads and tube ends have suffered, plates have been cracked and serious damage has resulted to the structure of the boiler. Many good engineers still consider protection by brickwork as desirable in order to avoid damage of this character.

Advantages.

The various advantages which have been claimed for oil fuel, and which experience, in greater or less degree, has confirmed, are as follows:

1.—*The Saving of Labor in the Fire-Room.*—This results from the fact that the fuel is handled mechanically, and from the absence of ash, clinker and soot. Due to these facts, the fire-room force may be reduced in marked degree, with corresponding saving in cost of operation. In several actual cases this reduction has brought the fire-room force down to from one-half to one-third its number with coal, and has reduced the entire engineering force to but little more than one-half its size with coal.

2.—*The Greater Evaporative Power of Oil, as Compared with Coal, Pound for Pound.*—The ratio may be taken at about 10 to 7, although a somewhat lower figure, perhaps, is preferable in estimates regarding the relative amount of fuel required in any given case. There results directly a decrease in the weight of fuel required in any given case, or an increase in the steaming radius with a given weight.

3.—*Better Stowage.*—The bunker capacity for a given service is decreased by the decrease in the weight of fuel, and because oil requires less space per ton than coal. The former may be estimated at about 36, and the latter at from 42 to 45 cu. ft. per ton. With given bunker volume, therefore, the steaming radius will be increased, due to both causes. Oil may also be stowed in double bottoms and other places which would not be available for coal or cargo.

4.—*Facility of Handling.*—With appropriate handling facilities, oil fuel may be placed on board ship with great rapidity, and much time saved in fueling as compared with coal. Experience has shown in cases requiring 24 hours and more for coaling, that the equivalent oil fuel can be taken aboard in from 6 to 8 hours, or even less.

5.—*Increase in Maneuvering Power with Naval Vessels.*—The rate of combustion is under immediate and ready control, and between wide limits may be varied at a moment's notice. This may be of the greatest advantage for naval vessels when the service is irregular, and demands for steam may rapidly pass through wide fluctuations.

6.—*Wear and Tear on Boilers.*—Under proper conditions the combustion of oil may be made practically smokeless and without the formation of soot, and since there is no ash, there is no occasion for a varying regimen of the boilers from one day's end to another. This is conducive to long life of the structure, provided local effects

in the furnace are avoided by complete combustion, suitable proportions and shielding, if needful. This situation may, however, easily pass from an advantage to a disadvantage provided the conditions for avoiding local effects are not fulfilled.

Disadvantages and Sources of Trouble.

1.—*Noise and Odor.*—These items relate to comfort and convenience rather than engineering considerations. Oil-fuel burners are noisy in varying degrees, and unpleasant odors are given off to an extent according to the grade of oil, the temperature and other circumstances.

2.—*Danger in Stowage and Handling.*—The question of danger depends largely on the tendency of oil to give off vapors which, when mingled with air, may produce an explosive mixture. This will depend on the grade of oil and the temperature to which it is exposed. Crude oil, with the lighter constituents unremoved and in a warm climate, will readily give off such vapors, and its use requires special care in connection with the ventilation of all spaces where they might collect and become mixed with air. Fuel oil, however, with the lighter constituents, benzine, naphtha, etc., removed by a first distillation, will not give off such vapors readily, and the element of danger is thereby largely removed. Due care, however, is always desirable in connection with ventilation and the prevention of the accumulation of any such vapors in inclosed spaces within the ship.

3.—*Wear and Tear on Boilers.*—Relative to coal, the wear and tear on boilers may be greater or less according to conditions. When due provision is not made for protecting the sheets of the furnace, and where the rate of combustion is such that the flames play directly upon exposed surfaces, the wear on rivet heads, tube ends and other exposed points may be serious. With some provision for protecting the points most exposed, and with space sufficient to permit the combustion to be completed before the gas reaches the sheets and exposed surfaces, these troubles may be avoided, and under favorable conditions, there is reason to believe that internal wear and tear may be made less than with coal fuel.

4.—*Uncertainty in Supply and Cost.*—The supply of oil fuel is somewhat uncertain, and the price fluctuates more widely than that

of coal. Recent oil-fields in Texas, California, Borneo and elsewhere, have added largely to the visible supply, and have provided a more definite surplus over that needed in other branches of industry, thus placing the use of oil more definitely on a fuel basis. The rate of supply, however, is fluctuating, and there is an uncertainty regarding the tendency in prices, especially if the world's demand for marine fuel should turn largely to oil. At present oil fuel can fairly compete with coal in many parts of the world, while in others, coal will be found the cheaper, counting in each case final operating expenses chargeable to the fuel account.

5.—*Minor Difficulties.*—Among minor difficulties connected with the use of oil fuel, mention may be made of the need of settling tanks, and the danger of putting out the flame if the water is not allowed to separate in this manner; the varying fluidity of the oil with changes in temperature, and the need of heating coils to insure, in all temperatures, the degree of fluidity needful for the best results at the burners; the liability of the burners to become clogged with sticky deposits of tar and carbon, thus interrupting their service and requiring cleaning; the liability of the furnace to become, at various localities, loaded with deposits of a similar character.

These troubles with deposits of tar and carbon depend much on the type of burner used, and on the extent to which the proper conditions for complete combustion are realized. Under good conditions and with the best modern types of installation, they have become quite negligible.

6.—*Limitations.*—One of the most serious limitations to the use of oil fuel, especially for naval service, has been the difficulty of attaining high rates of forced combustion. Until relatively recent years any attempt to force the combustion, and hence the output of the boiler, beyond relatively moderate rates, has been met with imperfect combustion, clouds of smoke, general inefficiency, and failure to realize the conditions desired.

It thus resulted that a greater output per pound of boiler or per square foot of heating surface, could be obtained by the use of coal rather than oil fuel. Further study of the problem, however, and especially the experiments carried on since 1902 by the Bureau of Steam Engineering of the United States Navy Department, have shown clearly that with a proper form of burner, proper proportions

in the boiler, and, above all, hot-air blast and draft, the combustion of oil can be forced to any desired amount, up to a full equivalent with coal, relative to the output for a given boiler. With proper provision for the needful air supply, delivered and mingled with the oil at a suitable temperature, it is found, therefore, that this limitation is quite satisfactorily removed, and that oil fuel, up to any rate of combustion which present demands are likely to require, may be used.

Economic Results.

The chief economic results are involved in the three relations:

1.—Oil to steam evaporated, or pounds of steam per pound of oil;

2.—Oil to indicated horse-power, or pounds of oil per indicated horse-power per hour;

3.—Cost of atomizing the oil, expressed directly in terms of steam, if steam is used as the atomizing agent, or in terms of steam required to operate compressors or fans, if air is used as the atomizing agent.

For the steam generated per pound of oil burned figures are found varying from 12 to 15 or 16. There are lacking reliable data and a tendency to assume the higher values. It is probable that values higher than 13 or 14 should not be counted on for sustained sea conditions. It follows from the known steam consumption of good marine engines that 1 i. h. p. will require from 1 to 1.3 or 1.4 lb. of oil. Here, again, the tendency is to extremes, and claims of oil consumption of less than 1 lb. per i. h. p. per hr. have been made; but, with good triple-expansion engines, with steam at about 180 lb., it is not probable that a figure lower than 1.2 lb. per i. h. p. per hr. in the main engine should be counted on for sustained conditions.

For the cost of atomizing, the figures, as may be expected, vary widely. Where steam alone is used several reliable tests indicate a value not far from 4% of the steam generated, or not far from ½ lb. of steam per pound of oil. Where blowers or fans are used, fewer direct data are available, but the indications are that the steam required does not differ greatly in the two cases. In the latter case,

of course, it is returned to the condenser, and its use does not become a drain on the fresh-water supply, as in the case of atomizing by steam direct.

Outlook for the Future.

It may be claimed that the various mechanical difficulties in connection with the burning of oil fuel have been fairly overcome, and that, by the best modern systems, such fuel may be used with efficiency and without mechanical disturbance of the regularity of the service. It should be noted, however, that modern experience has shown that different oils require different treatment in detail, and hence the minor arrangements of an adequate oil-fuel system must admit of variation to meet the peculiar demands of the fuel in hand. Furthermore, it should be noted that thus far practically all oil-burning installations have been made in connection with boilers designed originally for coal fuel, or at least designed with the furnace proportions and general arrangements which are the outcome of experience with such fuel. While this may seem desirable as a general provision for reversion to the use of coal in case of need, yet it can scarcely be doubted that, for the best results, the boiler should be designed with direct reference to the fuel which is to be used, and that in cases definitely committed to the use of oil fuel, the boilers should be designed in the light of such fact, and that with such boilers still more satisfactory results may be anticipated than with those in which the design is based primarily on the use of coal fuel.

With the various mechanical and engineering difficulties well in hand, the use of oil fuel becomes chiefly a question of supply, and of price, relative to coal. At certain points, as on the coast of California, oil fuel is decidedly cheaper than coal, at others, the price is more nearly equal, and at still others, oil is the more expensive. It thus results, due to the different geographical distribution of the oil- and coal-bearing fields, that there is certain to be a varying relation between the prices of the two, and that only in special types of service, or at specially favored points of supply, can oil fuel, at the present rate of output, compete advantageously with coal in price.

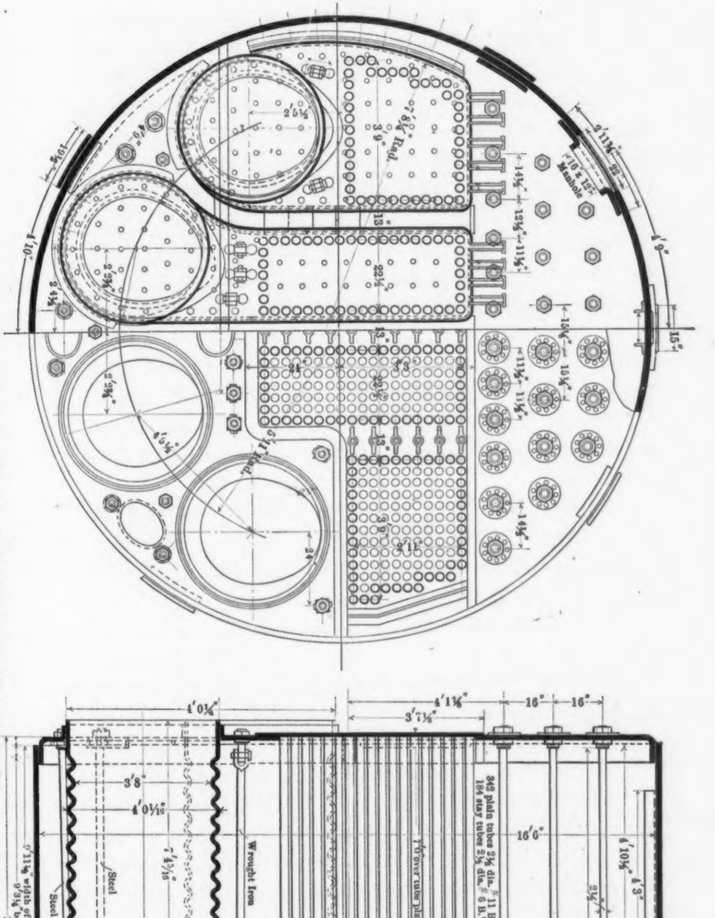
It should be noted that the price of oil and coal alone, compared with the output, in terms of steam generated, can rarely give a result which is fair to the former. The comparison should be made on the basis of the complete cost of a pound of steam with the two fuels, including not only the direct cost of the fuels themselves, but also all labor costs incident thereto, as well as interest, depreciation and insurance charges. These latter fixed charges will surely not differ widely in the two cases, under proper and favorable conditions for each, and the comparison should include primarily, therefore, the combined fuel and labor cost. With such a basis of comparison, and due to the saving of labor with oil, cases in which the cost of steam per pound may be more with oil than with coal, counting fuel cost alone, may yet show, on the broader basis, a fair advantage for oil and ample justification for its use.

Regarding the future supply of oil fuel no prediction can be made, but with anything approaching the present relations between the supply of the two great types of fuel, a gradual extension in the use of oil may be safely anticipated, as its practicability becomes more widely known, and as the conditions under which it may be utilized advantageously come to be understood more clearly.

Marine Boilers.

The most notable feature, in connection with the development of the marine boiler during the past decade, has been the relative rapidity with which the water-tube type has entered into practically full possession of the field of naval practice, and conversely the slowness of its progress in the field of general mercantile practice. At the present day, the water-tube boiler stands without a rival as typical of naval design, while the fire-tube or Scotch form still retains its hold as the representative boiler in the mercantile marine.

Furthermore, the latter type of boiler has become so definitely fixed in proportion and design, that only slight changes are to be found in representative and standard practice. Such changes as may be noted are chiefly the result of special conditions or demands, such as the adaptation of furnace details to the use of oil fuel, special furnace fronts and connections for hot forced draft, etc. Steam pressures with Scotch boilers have remained nearly stationary



FOUR-FURNACE SINGLE-END SCOTCH BOILER
FIG. 1.

for the decade under consideration. It would be, perhaps, more exact to say that the upper limit has risen but slightly, though there has been a slight rise in the average pressures used. While Scotch boilers have been built for 220-lb. pressure and even more, yet 180 and 200 lb. may be considered as better representing the upper limit of good practice, while the range from 170 to 180 lb. represents, perhaps, the middle field, and covers the larger part of present, standard, marine practice with boilers of this type.

Prevailing forms may be either single- or double- end, and with two, three or four furnaces in each end, according to the size and capacity of units desired. Two-furnace boilers range about 11 or 12 ft., three-furnace boilers, 13 to 14 ft. and four-furnace boilers, 15 to 16 ft. in diameter. Double-end four-furnace boilers of the largest size contain, perhaps, 180 sq. ft. of grate surface, from 6 000 to 7 000 sq. ft. of heating surface, and, with economical engines and under mechanical draft, will generate steam for 2 500 i. h. p. and more.

The materials of construction remain likewise substantially unchanged, and the general rules of the leading registration societies in relation to boiler construction, have undergone but slight change during the period under consideration.

Scotch boilers installed on shipboard with fittings and connections weigh from 35 to 40 or 45 lb. per sq. ft. of heating surface, or from 60 to 70 lb. per h. p. upward to 100 lb. or more according to the details of design and the degree to which they are forced.

With water, and in steaming condition, the corresponding figures range some 30 to 40% higher, according to the details of the case.

The following, taken from the last issue of the Rules of the American Bureau of Shipping, may be taken as representing standard specifications for boiler material at the present time, and the details show only moderate advances over those in force a decade ago:

"1.—Steel used in the construction of marine boilers must fulfill the following conditions:

Quality or process: Open-hearth.

Shell:

Phosphorus: Not more than 0.04 of 1 per cent.

Sulphur: Not more than 0.04 of 1 per cent.

Fire Box:

Phosphorus: Not more than 0.035 of 1 per cent.

Sulphur: Not more than 0.035 of 1 per cent.

"2.—Tensile Strength:

Rivet steel: 45 000 to 55 000 lb. per sq. in.

Flange steel: 55 000 to 65 000 lb. per sq. in.

Fire-box quality: 52 000 to 62 000 lb. per sq. in.

Shell steel: 55 000 to 70 000 lb. per sq. in.

Braces and stays: 55 000 to 65 000 lb. per sq. in.

Tubes: 52 000 to 62 000 lb. per sq. in.

"3.—Elongation:

Rivet steel: 28% in 8 in.

All other steel of 52 000 to 62 000 lb. tensile strength:

$\frac{3}{8}$-in. and less: 20% in 8 in.

$\frac{3}{8}$-in. to $\frac{3}{4}$-in.: 22% in 8 in.

$\frac{3}{4}$-in. and more: 25% in 8 in.

"4.—Cold-bending and quench tests:

Rivet steel:

Must bend 180° flat on itself without fracture on outside of bent portion.

All steel of 52 000 to 62 000 lb. tensile strength:

$\frac{1}{2}$ in. thick and under: Must bend 180° flat on itself without fracture on outside of bent portion.

Over $\frac{1}{2}$ in. thick: Must bend 180° around a mandrel one and one-half times the thickness of test piece without fracture on outside of bent portion.

Boiler Tubes:

Hydrostatic test to be applied to all tubes by maker:

Subjected to internal pressure of 500 lb. per sq. in. and when under pressure to be lightly hammered, especially on weld, if welded tubes are used.

Cold tests to be applied to not less than one tube in fifty, in the judgment of the inspector.

End of tube must allow of being expanded cold by conical drift to 10% excess on outside diameter.

Length of 4 in. must be flattened till sides are close, with weld (if the tube is welded) at the turn of the fold, and without showing fracture.

End of tube must allow of being flanged at right angles to the tube; width of flange $\frac{5}{16}$ in. from barrel of tube, and without showing fracture."

Regarding special materials, some attempts have been made to use nickel steel in boiler construction, but they have been too limited to have made any marked impression on the general practice in this field.

The shells of the Scotch boilers for the U. S. S. *Chicago* were made of a low nickel steel, and have given excellent results, but so little trouble is to be expected from the shells of such boilers that the good results reported furnish uncertain evidence regarding the value of the special material used. Some saving in weight could be effected in a boiler designed with reference to the full test strength of nickel steel, but this would be a step which few marine designers would care to take, with the information regarding the general adaptation of such material for boiler shells and like purposes which is at present in hand. Furthermore, the relatively high price of nickel steel renders its use of uncertain financial advantage, counting interest on added investment against the saving of weight which might be gained through the use of such special materials. The most serious question regarding material for steam boilers is, perhaps, not so much whether it is or is not a few pounds stronger than standard steel, but how it stands in regard to corrosion. The use or disuse of nickel and other special steels will thus be found to turn, perhaps, more on their standing relative to corrosion, than upon the fact of tensile strength alone. Quite recently there have been hopeful indications regarding the use of a high nickel steel for boiler tubes. Such material contains from 25 to 30% of nickel, and has shown remarkable results in strength and in resisting corrosion. The cost of such tubes is about three times that of carbon steel, but it is claimed that a life of from two to three times as long may be realized, with a saving in weight, and with a scrap value of the tubes estimated at about 20 cents per pound of nickel content. This seems to make a good case for the use of such material, and in any event, the possibilities indicated for the material are full of interest and importance with reference to this general problem of corrosion and deterioration in the heating surfaces of marine boilers.

The condition regarding the adoption of water-tube boilers has been already indicated. In the class of torpedo boats and destroyers this type of boiler had already become an established fact at the beginning of the decade under review, and the experience of later years has only served to confirm its special adaptability to the conditions presented by such designs. In battle-ship and cruiser

design, however, the fire-tube type still held the field, and it was not until the past decade that their use for vessels of these types became accepted as standard. At the present time, however, they have acquired practically the entire field of naval practice, and no other type is seriously considered in standard naval design. According to recent estimates, there is at present installed, or under construction, in ships of the various naval powers, a grand total of about 6 500 000 h. p. in boilers of this type.

Table 1* shows the division of this power among the leading naval powers of the world:

TABLE 1.

	Battle-ships and cruisers.	Torpedo boats and destroyers.
Great Britain	1 721 600	737 000
France	1 076 300	208 700
Russia	560 000	258 000
United States	547 500	146 300
Germany	443 700	200 900
Japan	220 500	121 600
Italy	201 000	82 800
Austria	144 000	....
Spain	....	28 500
Total	4 914 600	1 783 800

This rapid and complete change in policy regarding the type of naval steam generator marks an epoch in the annals of naval engineering, perhaps equal in importance to any which have preceded, or which are likely to follow, as long as steam remains the motive power for marine propulsion.

The general causes for the sharp difference in policy between the naval and mercantile marines, in respect to the type of marine boiler, may be realized, perhaps, by a comparison of the essential elements of the two types. For this purpose, attention may be called to the following tabular presentation, taken from a recent paper by Rear-Admiral Melville, Hon. M. Am. Soc. C. E., late Engineer in Chief, U. S. N.†

* *Journal*, Society of Naval Engineers, 1904, p. 292.

† "Causes for the Adoption of the Water-Tube Boiler in the U. S. Navy," *Transactions*, Society of Naval Architects and Marine Engineers, Vol. VII, p. 19.

ADVANTAGES.

Less weight of water.
Quicker steamers.
Quicker response to change in amount of steam required.
Greater freedom of expansion.
Higher cruising speed.
More perfect circulation.
Adaptability to high pressures.
Smaller steam pipes and fittings.
Greater ease of repair.
Greater ease of installation.
Greater elasticity of design.
Less danger from explosion.

DISADVANTAGES.

Greater danger from failure of tubes.
Better feed arrangements necessary.
Greater skill required in management.
Units too small.
Larger grate surface and heating surface required.
Less reserve in form of water in boiler.
Large number of parts.
Tubes difficult of access.
Large number of joints.
More danger of priming.

A comparison of these points of relative advantage and disadvantage indicates the conclusion that, for conditions of naval practice, the balance strikes in favor of the water-tube type, while for those of mercantile practice, the reverse is the case. The literature on this general subject during the past decade has been so profuse, and the relative points of the two general types of boiler have been discussed so exhaustively that further consideration may be limited to some special points with certain general conclusions.

Among the various navies, some fifteen of twenty different designs may be distinguished, roughly divided into two main classes of large-tube and small-tube or express boilers. The former have tubes from 2 to 4 in. in diameter, and with metal approximating $\frac{1}{4}$ in. in thickness, while the latter have tubes from 1 to $1\frac{1}{4}$ in. in diameter, and with metal about $\frac{1}{8}$ in. in thickness. The former represents the general type adopted for battle-ships and cruisers, and the latter that for torpedo boats and destroyers.

In regard to weight and space occupied, water-tube boilers of the heavier types show a moderate though valuable saving over those of the fire-tube type, and may be expected to weigh, without water, between 20 and 30 lb. per sq. ft. of heating surface, or from 50 to 80 lb. per i. h. p. In the lighter or express types of boiler the weights fall to about 10 or 12 lb. per sq. ft. of heating surface, or from 20 to

30 lb. per i. h. p., and in extreme cases to still lower figures. With water, these figures will range from 10 to 20% higher, showing in this feature one of the marked advantages of the type in the saving in contained water.

Water-tube boilers are commonly constructed for pressures of 200 lb. and upward, and to 300 lb. or more in rare cases. As far as the tubes themselves are concerned, there is always a large factor of safety at operating pressures, and the limiting conditions are determined rather by the drums or headers which form a part of the construction. In any event, the elements subjected to pressure are much smaller than in the Scotch boiler, and this gives to the type a distinct advantage in adaptation to the use of higher steam pressures.

One of the marked features of the water-tube type, as already noted, is the flexibility of design; and this has naturally led to the widest variety of forms, all calculated to fulfill, more or less completely, the special conditions imposed upon the marine steam generator. In this respect the water-tube type presents an absolute contrast to the fire-tube or Scotch type. The latter is the result of a long period of evolution, and represents a single definite design with but slight flexibility in detail. The term "Scotch" boiler calls up a definite and clear-cut type, and one with which the marine engineer, the world over, is entirely familiar. The term "water-tube" boiler, on the contrary, represents no fixed or permanent form, and is not yet the result of a long evolution of competing forms. It represents, rather, a broad name for any combination of tubes and drums, or headers, so arranged that they may be expected, with fire on the outside of the tubes, to generate steam on the inside, and to develop some kind of internal circulation through the tubes as an attendant circumstance.

Any geometrical combination which will, in some degree, fulfill these conditions may apparently be called a water-tube boiler. Recognizing these general facts, the Bureau of Steam Engineering, U. S. Navy Department, has wisely declined to declare itself definitely in favor of any one type of water-tube boiler, or to consider any one of the present types as a finality. On the contrary, it has adopted the policy of encouraging competition between representative boilers of various types, with the hope that in this trying-out

process some definite and final type may appear, or, rather, perhaps some few definite final types may appear, as best suited to the conditions for torpedo-boat design on the one hand and battle-ship or cruiser design on the other.

In a general way, the primary condition for torpedo-boat service is maximum output with minimum weight, while for battle-ship ser-

BABCOCK AND WILCOX BOILER - MARINE TYPE

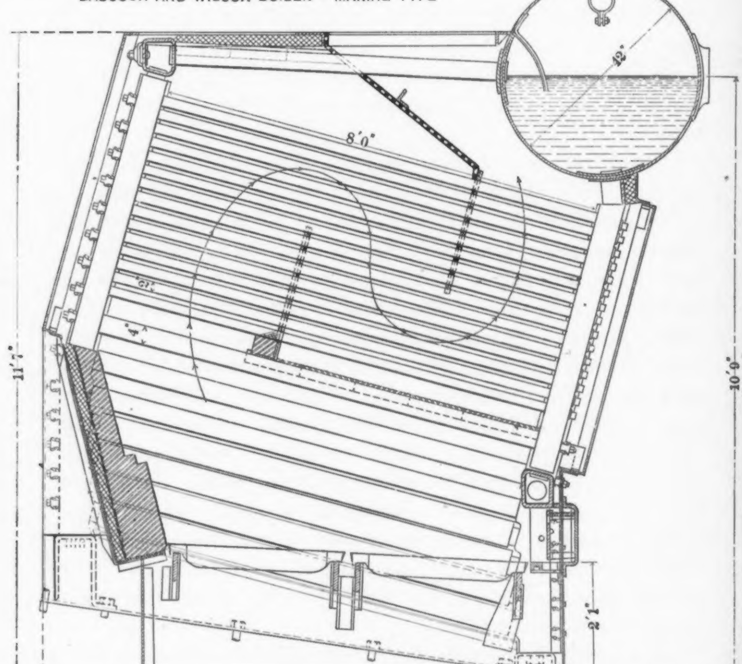
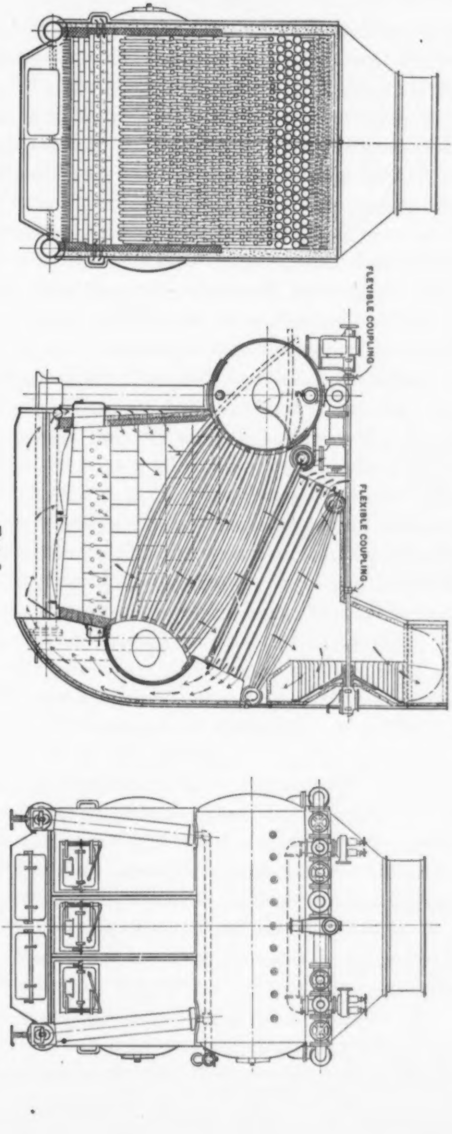


FIG. 2.

vice, conditions of maintenance and durability enter in as modifying elements, and lead naturally to a different type of construction. The U. S. Naval Bureau of Steam Engineering, in dealing with this question, has assumed that a satisfactory water-tube boiler for battle-ship service should have straight tubes, with provision for clean-



MOSHER WATER-TUBE BOILER
TORPEDO-BOAT TYPE

FIG. 8.

ing, and that the tube, in size and thickness, must be ample on the one hand to insure against clogging, and on the other against the corrosion normally to be expected in such cases. Due provision must also be made for circulation and for a reasonable reserve of water in drums or headers. The leading boilers exemplifying these characteristics, and used on United States naval ships of large size, are the Babcock and Wilcox and the Niclausse, with the Hohenstein as a newer and later type.

For torpedo boats, the requirements have been less restricted, and consequently vessels of this class have representative boilers of a wide variety of types and forms, for the most part, however, with bent tubes, and exhibiting a wide range in the solution of the problem of water-tube design for "express" service.

In European navies the definite adoption of the water-tube boiler has been no less marked than in the United States. In the British Navy the Belleville boiler was adopted as the first approved type. In the meantime a trying-out process has been going forward, and this type, together with the Babcock and Wilcox, the Niclaussé, the Dürr and the Yarrow large-tube have undergone careful comparative examination and trial. The reports published by the authority of the British Admiralty and giving the results of these tests, form a most valuable contribution to the literature of this general subject, and have served in no small degree as an aid and guide to others interested in the same problem.

In the Continental European navies, likewise, there has been some tendency, perhaps, to a relatively narrow restriction of types, and therefore to a lack of comparative results. Naval designers of all nations, however, are clearly convinced, as far as present indications may bear witness, that it is quite unsafe to accept as final any type which has thus far appeared, and that the proper attitude in each navy should be, by comparative test and trial, to determine the type or types best suited to the special conditions with which they may have to deal. With this as the accepted naval policy, an interesting and instructive period may be looked for during the next few years, in which we may hope for a more definite and authoritative solution of the problem of water-tube boiler design and operation than can be said to exist at the present time.

While it has been intimated that the water-tube boiler has made

but slow progress in the mercantile marine, this is by no means true of limited or special classes of craft. Thus, on pleasure craft, and especially on small launches, fast yachts, etc., the water-tube boiler has long established itself by virtue of the advantages peculiar to its type, and in all cases where the highest speed is of special importance, such type of boiler becomes a necessity of the design, in the same manner and for the same reason as with the torpedo-boat class. Again, for harbor tugs, ferry-boats, and to some extent with Sound and river boats, harbor, excursion and transport steamers, etc., the water-tube boiler has, for various reasons, commended itself to progressive designers, and in all these classes may be found this type of boiler, accepted as a satisfactory and efficient steam generator under the conditions prevailing in these fields of practice.

With large ocean-going passenger and freight steamers, the field which has always been peculiarly that of the Scotch boiler, but slight progress has been made, though here and there are to be found steamers of these types designed with boilers of the water-tube type. One of the most notable of such installations in the United States is to be found in the Great Northern steamships, *Minnesota* and *Dakota,* built for the Great Northern Railroad Company, and fitted with Niclaussé boilers giving an aggregate of about 10 000 i. h. p. for each ship. The experience gained with these boilers should prove of the greatest value in a study of their general adaptation to the conditions prevailing in mercantile practice, and it is to be hoped that the experience may be frankly and fully given for the benefit of the marine engineer and the mercantile marine at large.

In the general development of the water-tube boiler as a type, the leading features which have been made the subject of special study during the past few years, and which have served as the basis of the chief improvements, are the question of baffling and the provision of a combustion chamber. It was recognized in early experience with the water-tube boiler that, as usually, or naturally constructed, there was a tendency for the gases to short-circuit direct to the funnel base, and that the combustion, especially at high rates, was far from complete. Due to these causes, serious losses in economy resulted, and it was not until such matters were clearly understood that steps could be intelligently taken for improvement. While it is true that a square foot of heating surface in one boiler

is potentially as good as in another, it is none the less true that in any boiler the mere provision of heating surface is not enough. There must be provided, as fundamental requirements, conditions favorable to complete combustion on the one hand and an opportunity for the heating surface to become effective on the other. This seems to require, on the one hand, some form of combustion chamber or space between the fire surface and the tubes, where the gases distilled from the coal may become mixed with air and burned; and on the other, some adequate device for thoroughly spreading the current of gases through and among the tubes and preventing short-circuiting by the nearest route to the funnel base. A clear perception of these requirements has led to marked improvements in economy, and, even under high rates of combustion, with modern designs, economic results have been reached, which compare favorably with the best results from fire-tube boilers, and which, in themselves, indicate that the conditions for a proper control of these features are now well in hand.

While the future is always hard to foresee, the indications point strongly to the extension of the field occupied by the boiler of the general water-tube type. Out of the vast multiplicity of forms, some few are likely to emerge as superior in adaptation for the special conditions to be fulfilled, and from among these the marine designer will select in accordance with the circumstances of the case. It is difficult, however, to foresee indications of any early disappearance of the Scotch or fire-tube type. The qualities of this boiler are such as to specially commend it for many conditions of marine practice, and for many years it may be predicted that boilers of both of these two main types will divide the field of practice between them, the fire-tube type, perhaps, slowly losing ground as the rival type becomes perfected and reduced to more definite and narrow lines of variation, thus permitting its possibilities to be better realized and its requirements better understood.

Engines.

Type.—Aside from the steam turbine, which will be considered later, the type of steam engine suited to marine practice has undergone no essential change in the last decade. The type still remains

the familiar vertical, inverted, direct-acting, multiple-stage, condensing engine. But little change has come about in the relative utilization of compound, triple-expansion and quadruple-expansion engines. The typical marine engine still remains the three-stage or triple-expansion, using steam not far from 180 lb. boiler pressure, and with an area ratio between low- and high- pressure pistons of 6.5 or 7 to 1, giving a total expansion ratio, allowing for high-pressure clearance, of not far from 10 to 11. The compound engine using steam of 120 to 150 lb., and with an area ratio between the low-pressure and high-pressure cylinders of about 4, giving some 6 or 7 total expansions, is still found on some small steamers, tug-boats, paddle-wheel steamers, and other special-purpose craft, while, on the other hand, the quadruple, using steam at 180 to 250 lb., or even higher, and with an area ratio between the low-pressure and high-pressure cylinders of 8 to 9, giving from 12 to 15 total expansions, is now met with on transatlantic liners and other mercantile craft where economy is of special importance, in naval practice especially with torpedo boats and destroyers, on fast yachts and on other craft where high-pressure steam is used, and where the best economy at full power is a matter of some importance. On the whole, however, the quadruple-expansion engine has not made the relative gain, compared with the triple-expansion, which ten years ago it seemed reasonable to anticipate, and to-day the triple-expansion engine may claim to stand as the normal and typical engine for the average conditions of marine practice. It may be also said that in some cases where the quadruple-expansion engine has been used, the choice has been determined by the advantage which four cranks gives for balance with regard to inertia forces, rather than by the expected gain in economy. From this viewpoint, if four cranks are to be used, the choice must be made between the four-crank triple with two low-pressure cylinders, each giving about half the power of the other two, and the four-crank quadruple with a more equable division of power. Under these conditions, the quadruple may be chosen rather than the triple, aside from the further advantage which might be expected from higher economy.

The chief reasons for the relatively slow advance of the quadruple into more general favor can only be referred to in passing, and may be summarized in the single statement that, with equal

steam pressures, or in other words, under equal conditions, the gain in economy of the quadruple over the triple is but slight, while for the same power it is heavier, and has a greater number of parts, and, therefore, is more expensive in construction and maintenance. The general continuance in favor of the triple-expansion engine as the typical marine engine may then be taken simply as an indication that, in the general consensus of opinion, the relatively small advance in economy may be, for average conditions, too dearly obtained in terms of the disadvantages previously noted.

Besides the simple direct three- and four- crank types of triple- and quadruple- expansion engines, respectively, there exists a great variety of other arrangements. The low-pressure cylinder, or the high, or even the intermediate cylinder of a triple-expansion engine may be divided into two cylinders of half volume each, and these may be combined and set up in various ways on three or four cranks. Similarly, the various cylinders of a quadruple may be subdivided and combined in various ways giving a four- or five-crank engine. The purpose of these various subdivisions and recombinations may be threefold:

1.—In dividing the low-pressure cylinder to reduce the size of an otherwise undesirably large casting;

2.—To realize by recombination as equable a division of power as possible among the various cranks;

3.—To increase the number of cranks in order to be able to deal better with the balancing problem. Mention of this reason has been already made in connection with the four-crank triple-expansion engine, and further reference will be made at a later point in connection with the general subject of the balancing of inertia forces.

Steam Pressure.—The general trend of steam pressures with marine steam engines has been already mentioned in connection with the subject of boilers. The typical triple-expansion engines are using steam of about 180 lb. gauge pressure, while for quadruples, a pressure of not less than 200 lb. is preferred. With water-tube boilers steam is generated at a pressure of 225 to 250 or even 300 lb., and is used at the engines usually with some reduction through a reducing valve, or by wire-drawing, in order to decrease

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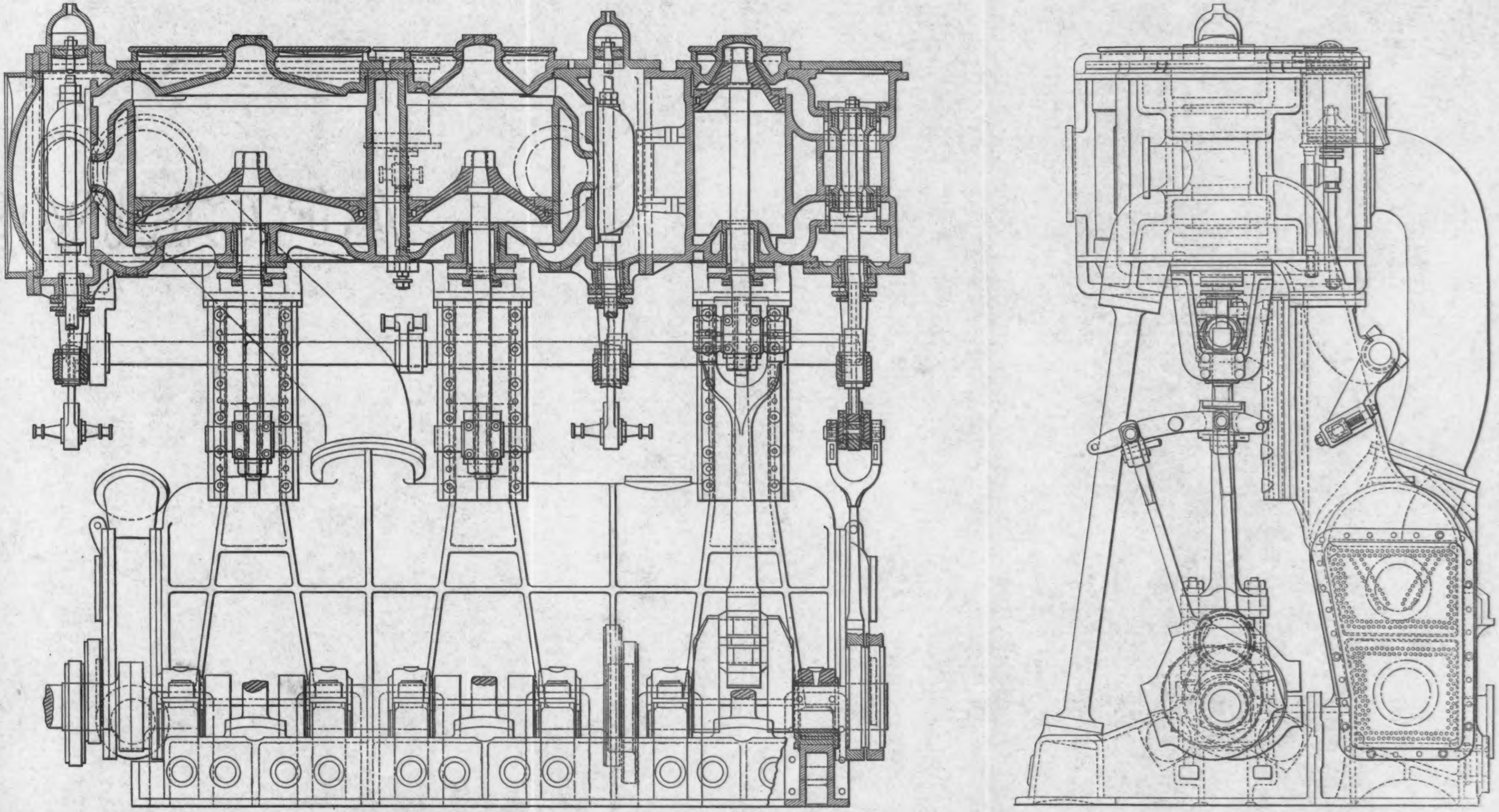

THREE CYLINDER TRIPLE EXPANSION ENGINE. MERCANTILE TYPE.

the amount of entrained moisture, and thus give a dryer steam at the engine than if delivered under full pressure.

The general trend, with regard to pressure, has been quite slowly upward during the past decade, and it would appear, under present conditions and with present materials and modes of construction, that the upper limit of practicable and economical pressures is being approached. It is well known, of course, that radiation and conduction losses increase with higher pressures and temperatures, while there is an increase in the general difficulties of use and in the character of the supervision and routine care which high-pressure steam requires. It appears that, under existing conditions, the relatively small gain to be derived from increased pressures is very closely balanced by these attendant losses and disadvantages, and that only slow increase in pressures may be looked for as long as engineers must operate under the conditions which prevail at the present time.

Piston Speed.—In piston speed, likewise, there has been a gradual and steady trend upward, more particularly in naval designs for torpedo-boat and destroyer types. In the mercantile marine for freight steamers, and, in general, for operation under relatively easy conditions of speed and power relative to displacement of ship, piston speeds of 600 to 700 ft. per min. prevail, while under more exacting conditions with vessels of the same type, designers freely advance to piston speeds of 800 ft. and more, if necessary. For combined freight and cargo steamers and for passenger steamers reaching upward into the class of trans-ocean liners, piston speeds of 900 to 1 000 ft. have remained practically standard, with slight tendency upward in individual cases. In naval designs for cruiser and battle-ship engines, piston speeds of about 900 ft., rising to 1 000 ft. in special cases, have prevailed. In torpedo-boat and destroyer practice, the speeds have risen to about 1 200 ft. as a maximum, while, in rare cases of fancy yacht design, there have been piston speeds of 1 300 to 1 400 ft.

The limitations met by the engineer, in the matter of piston speed, arise from two sources:

1.—Difficulties with lubrication, and with general wear and tear, arising from high velocity of rubbing surfaces;

2.—Increase in the amount of the inertia forces and in the troubles to which they may give rise.

With general improvement in methods and details of construction, and with a better understanding of the problem of balancing, these difficulties have gradually yielded, and have permitted a corresponding gradual elevation in the practicable upper limit of piston speed. There seems no reason for setting any special limit to advances in this direction, and a slow though steady increase in piston speeds may presumably be looked for, distributed all along the line of general marine practice, and reaching upward to figures which present data can scarcely serve to foretell.

Weight and Space per Indicated Horse-Power.—In these items there has been likewise a moderate and steady gain throughout the decade under consideration, conditioned in part on higher pressures and piston speeds, and in part on more economical methods of design. The general dimensions of an engine are dependent on steam pressure and piston speed, while the detail or scantling dimensions are dependent on the general load conditions, on the materials of construction and on the economy of design. Aside from the load conditions there have been advances relative to all the other items which have tended toward a reduction in general weight and space occupied per unit of power developed. For the main engines without auxiliaries, representative figures for the mercantile marine range from 50 lb. or below to 100 lb. or above per i. h. p. Battle-ship and cruiser designs are covered by figures ranging perhaps from 40 to 60 lb., with a tendency toward the lower side of the range based on full power rating. In torpedo-boat and destroyer types, as well as in the class of fast yachts and racing machines, the figures range down to about 20 lb., rising to 30 lb. or, in extreme cases, falling to about 15 lb.

Decrease in space occupied has gone hand in hand with decrease in general size and weight, and only, perhaps, to the extent to be accounted for by the same general causes already noted in that connection. The use of radial valve gears, for the purpose of reducing the length of the engine, has not met with as general favor or extended adoption as seemed reasonable to anticipate when they were first brought to the notice of designers of marine machinery, and the Stephenson link still maintains its position as the leading type of marine valve gear, even though it may entail a slightly increased length of engine as compared with the radial type of gear.

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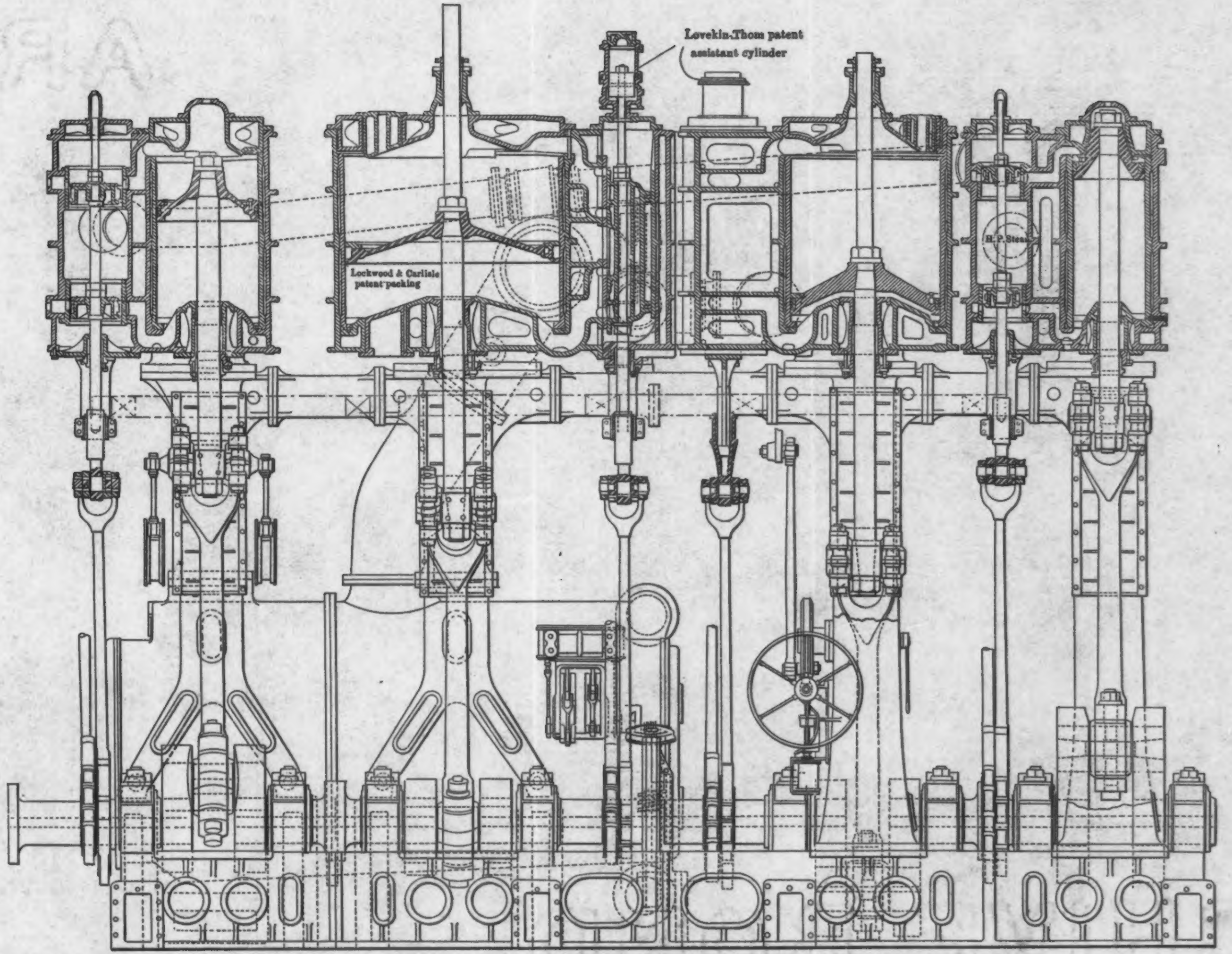

FOUR-CYLINDER QUADRUPLE-EXPANSION ENGINE, MERCANTILE TYPE.
LONGITUDINAL SECTION

Materials of Construction.—The standard materials for the construction of marine engines have remained during the past decade without important change, and comprise cast iron, cast steel and forged steel, with special anti-friction metals for bearings and rubbing surfaces. Cast iron still remains the standard material for cylinders and valve chests, flat and piston valves, and largely for cast columns and bed-plates, as well as for piston and valve packing rings. There have been great advances made in the moulding and casting of relatively complex forms in cast steel, and within reasonable limits almost any form desired by the designer may now be provided in this material. Thus far, however, its use in the marine steam engine has been limited to columns, bed-plates, bearing caps, pistons, cross-heads, propeller blades, valve-stem guide brackets, link-blocks and other miscellaneous parts which would naturally be made in cast metal, and for which the superior strength or stiffness of the steel is an advantage of moment. In general, cast steel does not give a good bearing surface, and therefore is avoided for all rubbing and bearing surfaces. Forged steel remains the standard material for cylindrical columns, for piston rods, connecting rods, valve stems, links, eccentric rods, crank-shafts and shafting, and in general for all moving parts, particularly where its superior strength and safety under varied and irregular stress are features of importance. The chief advance in these particulars has been in methods of forging and working steel shafting and other like parts, and particularly in forging and oil-tempering or otherwise treating nickel steel for purposes of this character. Reference has already been made to nickel steel in boiler construction, and to the small extent to which such material has thus far been utilized for such purposes. In engines, however, and particularly in naval and other high-class work, the case is quite different, and nickel steel is used freely for those parts naturally made of forged material. The steel thus used in engine construction is of low-nickel content, ranging from 2 to 4%, and with physical properties as indicated in the specifications for such material given in Table 2.

Structural Details.—There has been but slight change during the past ten years in the character of the structural details of marine-engine construction. The general character of the types of engines used has become so definitely established that as long as the recipro-

cating engine remains in use but little further change may be expected in the general form and character of the parts and in their mutual relations in the structure as a whole. Perhaps the most notable item in this respect is the definite status acquired by the hollow tubular member as a structural detail. One can now find in advanced marine practice hollow line and crank shafting, hollow crank-pins, cross-head pins, piston and connecting rods, and hollow forged cylindrical columns. There are two advantages of such construction:

1.—A better assurance of the integrity of the metal secured by boring out the central core where flaws are most likely to occur, and by the opportunity of thus inspecting the material on the inner as well as on the outer surface;

2.—A saving in weight.

TABLE 2.—STANDARD SPECIFICATIONS FOR FORGED STEEL.

Class.	Material.	Treatment.	Minimum tensile strength, in pounds per square inch.	Minimum elastic strength, in pounds per square inch.	Minimum elongation. Percentage in 2 inches.	MAXIMUM AMOUNT OF:		Cold bend about an inner diameter of:
						P.	S.	
High-grade..	Open-hearth nickel steel.	Annealed and oil-tempered.	95 000	65 000	21	0.06	0.04	1 in. through 180°.
Class *A*......	Open-hearth, either nickel or carbon steel.	Annealed. Oil-tempered optional.	80 000	50 000	25	0 06	0.04	1 in. through 180°.
Class *B*......	Open-hearth carbon steel.	Annealed.	60 000	30 000	30	0.06	0.04	½ in. through 180°.

It is a well-known result of the mechanics of such members subjected to either cross-breaking or torsional stress, that the increase in external diameter necessary to compensate for the removal of the inner core, is relatively very small, and that in consequence the tubular member is lighter than the solid member of equal strength. In illustration, it appears from the usual formulas that for the case in which the diameter of the hole is one-half that of the shaft, the increase in

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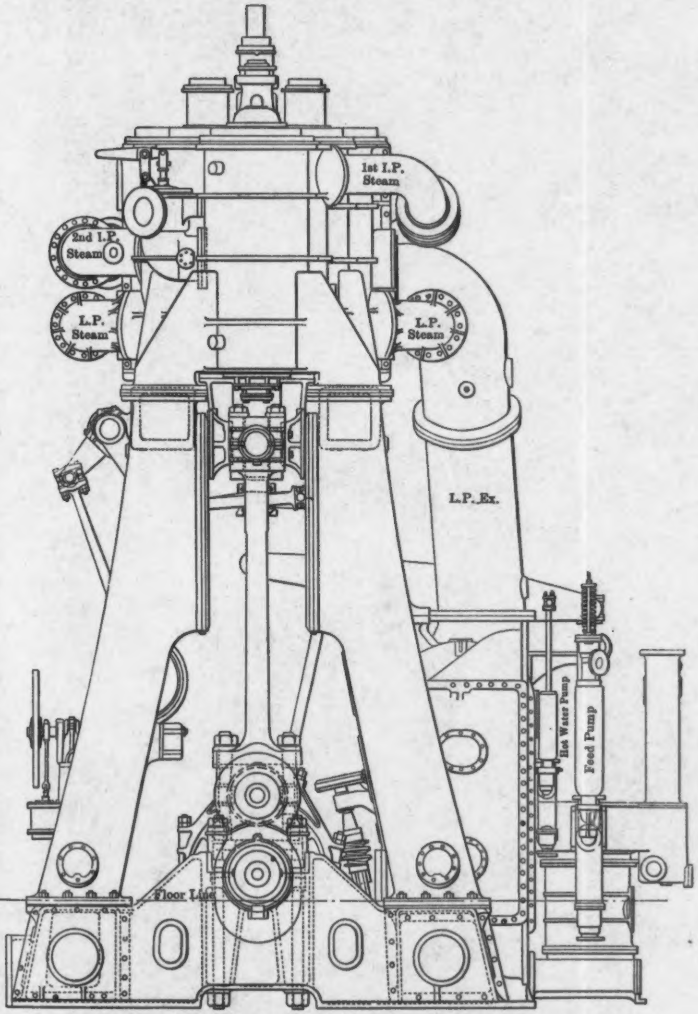
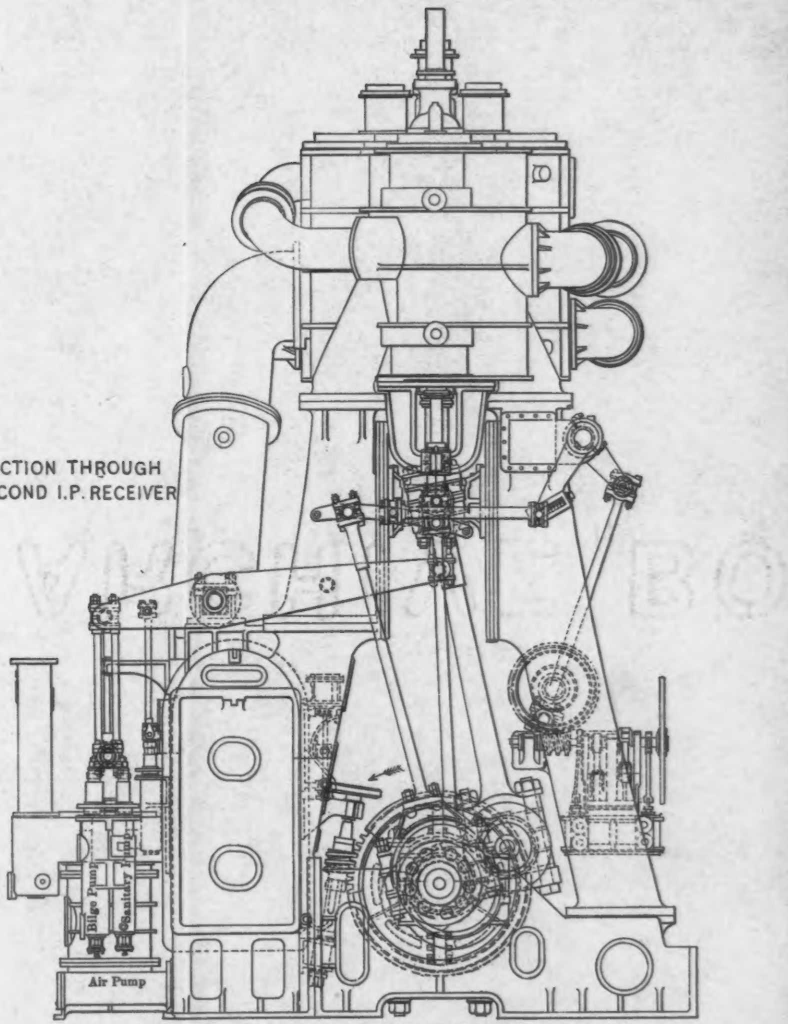


FOUR-CYLINDER QUADRUPLE-EXPANSION ENGINE.
VIEW LOOKING FORWARD



FOUR-CYLINDER QUADRUPLE-EXPANSION ENGINE
VIEW LOOKING AFT.

outer diameter over that of an equivalent solid shaft is only about 2% of the latter, while the saving in weight will amount to about 22% of the latter.

Naturally, hollow cylindrical members are more costly than solid, but, notwithstanding this fact, their advantages have secured for them a definite place in the naval and other advanced practice of the day.

In the construction of bearings, and in connection with the general subject of lubrication, there has come about a more definite and assured status of some special white, or anti-friction, metal as a bearing surface, of some regular and systematic method of distributing lubricant to the various bearings, and of the hollow bearing block with internal water circulation in cases of severe demand. Internal lubricant is still used, though efforts have been made to dispense with it, on account of troubles arising from oil in marine boilers. Special materials have been used for piston rings, and graphite lubricant has been used with cast-iron rings, especially in some cases of design of the torpedo-boat engine type, and with some degree of success; but, on the whole, internal lubrication for the cylinders still holds its place as a feature of average operating practice.

Economy.—In step with gradually advancing steam pressures, with better proportioned designs, with greater care in preventing the loss of heat by radiation and conduction and by waste steam from auxiliaries, there has resulted a gradual advance in the economy of the marine boiler and engine as a combined unit. Stating economy in terms of coal consumption per indicated horse-power per hour, the figures, realized under average conditions for triple-expansion engines and corresponding steam pressures, range from 1.5 upward to 1.7 or 1.8 lb., with less favorable conditions, and downward to little more than 1 lb. under exceptionally favorable conditions, and with advantage taken of every means available for decreasing heat waste in both engine- and fire- rooms. With quadruple-expansion engines, and a correspondingly higher steam pressure, the consumption may be expected to range from about 1 lb. as a minimum, upward to 1.5 lb., according to the conditions of operation and the extent to which heat wastes are prevented. These figures relate more especially to the use of common or saturated steam, such as is provided in the usual case of marine practice.

One of the most interesting and significant features of the past decade, having relation to economy in the marine engine, is found in the development in the use of superheated steam. The advantages of superheated steam from the viewpoint of economy have long been understood, and attempts looking toward its use were made early in the development of marine engineering. Serious difficulties, however, were met with both in the corrosion and wear and tear on the superheaters, and in connection with the lubrication of the engine, and with the moderate degree of superheat attained the advantages realized hardly balanced the disadvantages, and the use of superheated steam fell into general disfavor. More recently, and in marked degree within the last decade, renewed attention has been given to the use of superheated steam in general power-plant practice, especially in Continental Europe, and the more serious difficulties have been overcome to such a degree that its use may now be considered as entirely practicable, and mechanically within the reach of the engineer whenever he may consider it desirable. In marine practice its use on anything approaching a representative scale is confined to comparatively few cases, more notably on the *Inchmona* and *Inchdune*, and more recently on the *Queensborough, Atlantic* and *Britannic*. In the latest type of marine superheater, as installed on the *Atlantic* and *Britannic*, the superheating elements, consisting of waved tubes connected by headers, are placed back of the boilers and connect with the top of the combustion chambers through suitable openings. The casing containing the coils is well insulated, and connects by a special conduit to a separate funnel placed inside the main funnel. A small steam-turbine-driven fan is used to induce a draft through the superheating chamber, and this, together with suitable dampers, provides the necessary control.

Present experience indicates that the best results with superheat may be expected with moderate steam pressure and high superheat, rather than high steam pressure and less superheat. Thus, in the earlier installations, steam was carried at a pressure of 267 lb., and was superheated about 60°, bringing the steam to a temperature of about 465 degrees. In the latter installations, steam is carried at about 160 lb. or 370°, and is then superheated some 130°, raising it to a temperature of about 500 degrees. Experience indicates that,

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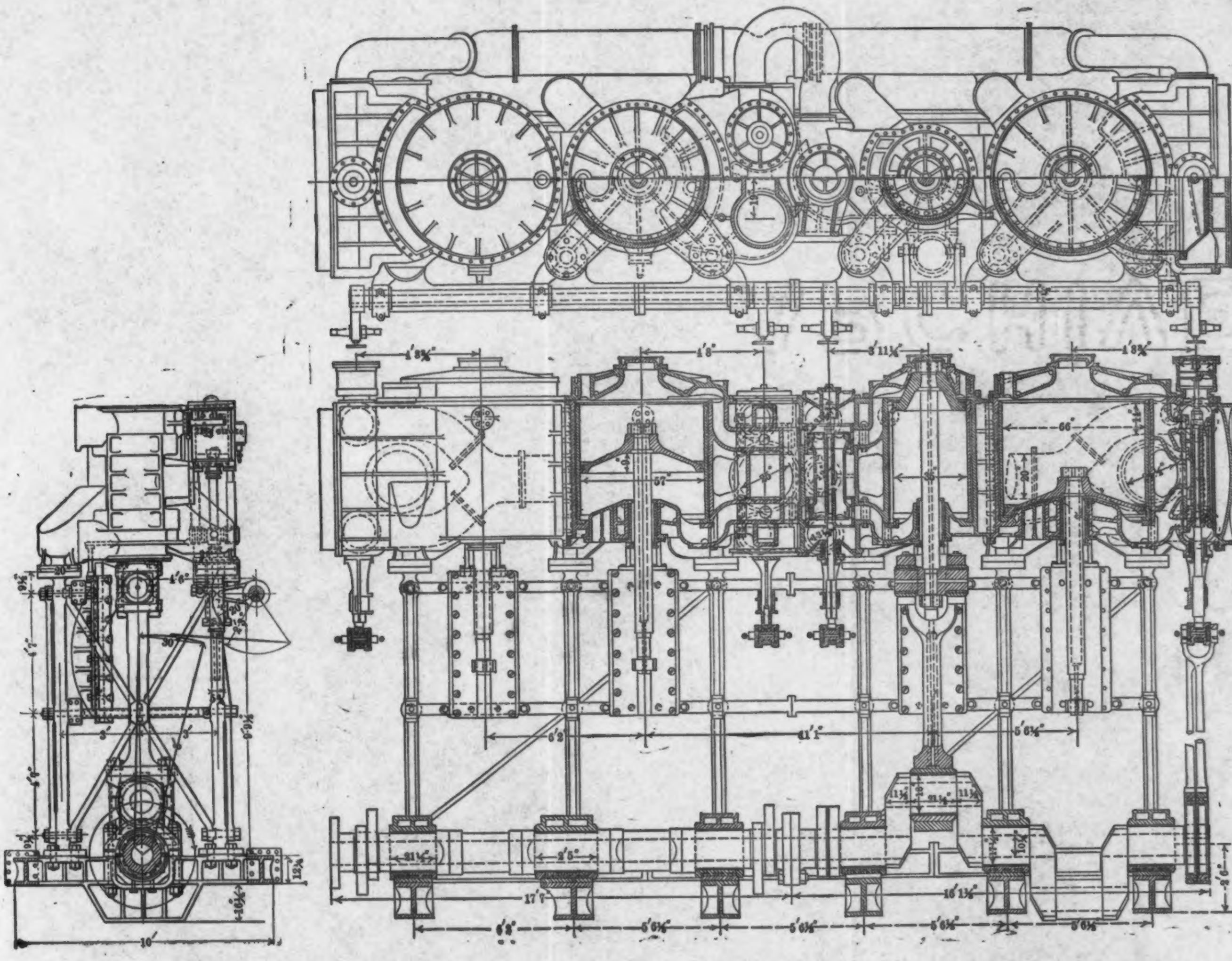
FOUR-CYLINDER, TRIPLE-EXPANSION ENGINE, NAVAL TYPE.



roughly speaking, somewhere about 1% gain in economy may be expected for every 10° superheat above the temperature for 160 lb. saturated steam. Results from such installations indicate that under these conditions the power may be developed continuously for a voyage at about the rate of 1 lb. of coal per i. h. p. per hr.

These results are of the highest significance to the marine engineer, and point the way to better economy in such cases as may justify the additional investment of capital and weight which are required.

Balancing Inertia Forces.—One of the most notable subjects of investigation during the past decade, and one which has perhaps furnished more literature than any other single item, is that of the balancing of inertia forces in the marine steam engine. The necessity for such examination, and the importance of these forces as a feature demanding serious attention, has become more and more pronounced with the increase in rotative speeds, and with the general increase in power per ton of displacement of ship.

These various investigations, experimental and theoretical, have served to show that ship vibrations in a vertical plane may arise from either an unbalanced vertical force or rocking moment, both manifested directly at the engine; that horizontal unbalanced forces and moments may also produce similar, though, in general, less serious disturbances; that variations in rotative effort and corresponding variations in rotative speed at the engine as well as variations in rotative resistance at the propeller, may give rise to torsional or angular vibrations; that an unbalanced propeller will give rise to a periodic radial force, the results of which will usually be manifested chiefly as vertical vibrations, and be most pronounced at the stern of the ship; that these various vibrations, and particularly, the vertical and torsional modes, may exist in complex combinations of successive orders as regards period, built on the primary vibration with a frequency equal to the revolutions of the engine; that on twin-screw or triple-screw ships, these various influences, coming from each engine and propeller, may combine in the most complex modes in the final resultant vibration.

From the mere recital of these various items which may enter into the resultant ship vibration, the complex character of the problem will be sufficiently manifest. Only the briefest mention of the means

available for the reduction and control of these disturbances can be given here.

In a two-crank engine, with cranks at 180° and equal weights of moving parts, forces of the 1st, 3d, 5th, etc., orders are individually balanced, while those of the 2d, 4th, etc., orders accumulate individually together. This arrangement of cranks, however, gives a very uneven turning effort, and is always avoided in marine practice.

In a three-crank engine, with cranks at 120° and equal weights of moving parts, forces of the 1st, 2d, 4th, 5th, etc., orders are individually balanced, while those of the 3d, 6th, etc., orders accumulate individually.

In a four-crank engine, with cranks at 90° and equal weights of moving parts, forces of the 1st, 2d, 3d, 5th, 6th, 7th, etc., orders are individually balanced, while those of the 4th, 8th, etc., orders accumulate individually.

In none of the preceding cases, however, are the moments balanced, and, in general, four cranks with unequal distribution of crank angles and unequal weights of moving parts, give the minimum condition permitting of the balance of moment.

In addition to the forces developed by the main moving parts comprising the piston, piston-rod, cross-head, connecting-rod and crank, there are also corresponding forces due to the valve gear and attached pumps, if any, which must also be reckoned with.

A primary force, or a corresponding primary moment, may always be balanced by a rotating shaft weight.

It results as follows:

1.—A satisfactory balance of primary force can be readily made with any given engine by the determination of a suitable shaft counterweight;

2.—Such weight cannot, in general, be depended on to balance primary moment at the same time;

3.—A satisfactory balance of primary and secondary forces may be made with a three-crank engine with unequal weights of moving parts, by accepting an unequal distribution of crank angles around the circle;

4.—A satisfactory balance of primary and secondary force and primary moment may be made with a four-crank engine

PLATE XIII. VOL. LIV. PART C.
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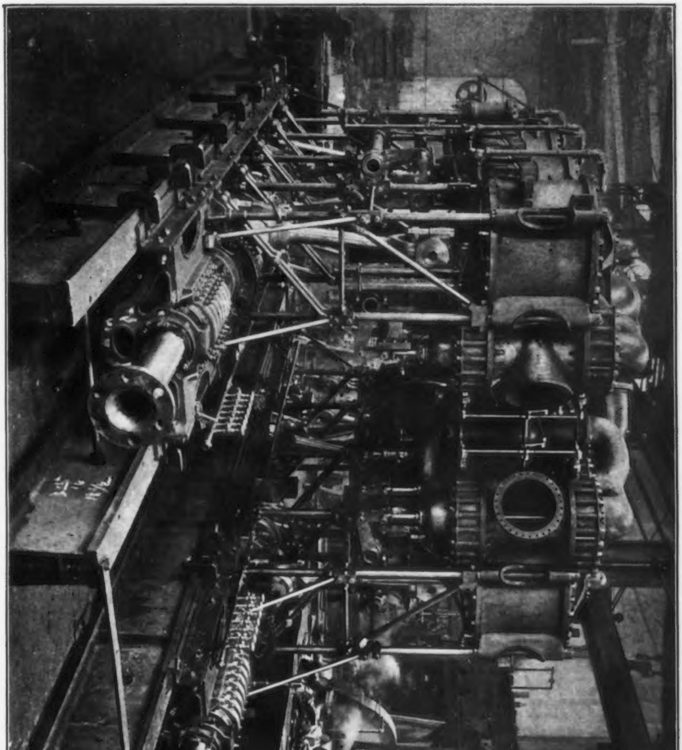

TYPE OF MODERN TORPEDO-BOAT ENGINE.

with unequal weights of moving parts by accepting an unequal distribution of crank angles around the circle.

This latter principle forms the basis of the so-called Yarrow-Schlick-Tweedy system of balancing, a method which has gained an established place in standard practice, and which has given good results when intelligently applied with reference to the various circumstances of the case.

In all cases due regard must be paid to the forces which come from the valve gear, inasmuch as the resultant of such forces may prove of serious importance if allowed to join additively with the resultant of the forces due to the main moving parts, while much may often be done toward balancing the main resultant by a judicious disposition of the various forces arising from the valve-gear parts.

While the problem of balancing had been worked out in a fairly satisfactory manner before the beginning of the decade under consideration, yet credit must be given to the last ten years for furnishing far more complete and satisfactory working theories and methods than were previously available, and for showing, by repeated demonstration, the possibilities as well as the limitations of the practical methods at the service of the designer of marine engines in dealing with problems of this character.

The Steam Turbine.

Reference has been made to the steam turbine as a form of motor already assuming prominence in the marine field. This development has come about entirely within the past decade, the pioneer installation being that of the Parsons turbine on the experimental boat *Turbinia* in 1897. As the point of departure the chief particulars of this boat may be recalled:

Length	100 ft.
Displacement	40 tons
Indicated horse-power	2 100
Revolutions	2 200
Speed	32.75 knots
Propellers	9, distributed 3 each on 3 shafts.

This boat was followed shortly by two destroyers, the *Cobra* and *Viper,* both unfortunately wrecked, and then by the Clyde steamer, *King Edward the VII,* and later by the *Queen Alexandra, Princess Maud,* the channel steamers, *Brighton* and *Queen,* a Canadian lake and river steamer, several yachts, further destroyers, the Irish Channel steamers, *Londonderry* and *Manxman,* and last, and of perhaps highest importance, by orders placed for turbine machinery for a transatlantic cargo boat for the Allan Line, and still more recently by the decision to use such machinery for the two new Cunard liners to be built under subsidy from the British Government.

The development thus far noted is all to the credit of the Parsons turbine and to British enterprise in taking up this type of motor for marine purposes. On the Continent of Europe some progress has also been made, and the French have at least two turbine-propelled

MARINE STEAM TURBINE, PARSONS TYPE

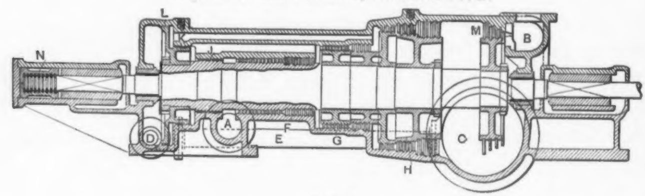

FIG. 4.

torpedo boats, with machinery of the Rateau type. In the United States there has been thus far the yacht *Revolution,* with turbines of the Curtis type, and plans are under development in the Navy Department for two turbine-propelled 3 000-ton scout ships.

The keen interest which this development of the steam turbine as a marine motor has aroused has, within the past few years, given rise to an abundant literature, both descriptive and expository, relating to the turbine; and the purposes of this paper will not permit of more than a brief *résumé* of the more important points, both of advantage and disadvantage, with some reference to the points wherein the turbine represents a type of prime mover different from the steam engine, and, therefore, marking the origin of a distinct line of progress.

As a mechanism the turbine differs greatly from the recipro-

cating steam engine. There is one rotating piece as the sole moving part, and the entire character of the construction is vastly more simple in many ways.

As a means whereby some part of the energy of steam may be transformed into mechanical work, the resulting transformation history of the steam is also entirely different from that in the reciprocating type of engine. In the latter the steam operates by pressure against a piston moving within a cylinder. Under these conditions the steam gives up some part of its molecular energy to the piston, which recedes under the molecular bombardment constituting the pressure, and there is thus effected at the surface of the piston a transformation of molecular energy into mechanical work. The point to be especially noted is that the energy which is thus transformed is the kinetic energy which constitutes heat, and which is assumed to be due to an orbital motion rather than to one of translation.

On the other hand, the steam turbine, in order to effect its peculiar mode of transformation, requires, first, that the molecular or heat energy of the steam be transformed in whole or in part into the kinetic energy of translation embodied in a stream of molecules with a definite component motion in one direction, and constituting a so-called jet or flowing column of steam vapor. Once this transformation is effected as a preliminary step, the turbine then acts by the interposition of its curved vanes in the path of the flowing jet, producing a deviation in the direction of the latter, and receiving therefrom a reactive force which, under proper mechanical conditions, will produce rotation of the rotor or moving member of the turbine, and as a result of which a part of the velocity and kinetic energy of the jet is lost by transfer to the rotor. In this manner, by a double step, the desired transformation is effected from the heat energy of the steam to the mechanical energy delivered to the rotating member of the turbine.

The chief varieties of steam turbines depend on the details of the process by which these general operations are carried out. Thus, the entire transformation possible from orbital velocity to jet velocity, and thus from heat energy to energy of translation, may be effected either by one step or in a succession of stages. Again, the second transformation, from the energy of the jet to the mechanical

work in the rotor, may be effected either by a single set of vanes, and thus, by what may be termed a single operation, or by a continued series of vanes, and thus by a continued series of operations, or in a continued series of stages.

In all cases the transformation from heat energy into what may be called jet energy is effected by allowing the steam to expand against a pressure lower than its own, and thus to develop the velocity of jet by what may be termed a rectification of the orbital velocity of the molecule, and its direction along the line of least resistance.

The simplest ideal means for accomplishing this transformation, therefore, is a tube or nozzle directing a line of flow from a chamber of high pressure to one of low pressure, as, for example, from a steam boiler to the atmosphere.

The simplest ideal means for accomplishing the second transformation, that from the jet energy to the mechanical work manifested in the rotor, is by a series of curved vanes or faces attached to or formed in the periphery of a rotating disc.

There are naturally many questions connected with the form and dimensions of the nozzle, and with the form, dimensions, distribution and velocity of the vanes, in order to insure the maximum degree of transformation in each case, but these are questions of detail aside from the purpose of this paper.

The combination of a suitable nozzle with a single set of corresponding vanes thus constitutes the simplest form of turbine, and is illustrated in the De Laval type.

Since in this type the entire possible transformation from orbital to jet velocity is effected at one step, the velocity of the jet is excessive, and this requires high peripheral and high resultant rotative speeds for the realization of a satisfactory efficiency. Due to this fact, the rotor is geared down to a driven part, commonly by a ratio of 10 to 1, and in this manner the speed of the latter is kept within reasonable limits. Turbines of this type have shown efficiency, and have commended themselves for many special purposes connected with the running of auxiliary machinery such as electric generators, ventilating fans, etc. It is, however, difficult to make machines of this type in units larger than from 300 to 500 h. p., and this fact, together with the need of gearing between the rotor and driven part, has prevented their serious consideration for propulsive purposes.

Various other types of turbines, so-called compound in character, may be developed by combinations of step-wise or semi-continuous methods of carrying out the two fundamental transformations of energy. Thus, in the Parsons type, the steam rushes from the steam supply to the condenser through the annular space between the wall of a long cylindrical casing and the contained rotor, increasing the cross-sectional area from the entering to the delivery end. This annular space thus constitutes in effect a gigantic nozzle within which the steam is continually undergoing Transformation (1) as it passes from one end to the other. Within this annular space are alternate rows of fixed and movable vanes, the former attached to the casing, the latter to the rotor. The steam is thus directed and redirected upon the successive rings of moving vanes, each of which extracts some part of the developed jet energy, and thus the two transformations, (1) and (2), go forward, in a measure, hand in hand. It must not be assumed that the increase in sectional area of the effective passage for the flow of the steam is uniform. It is controlled by three factors:

1.—The varying diameter of the casing increasing by steps from one end to the other, and, therefore, the varying circumferential length of the annular passage;

2.—The varying length of the vanes and, therefore, the varying depth of the annular passage;

3.—The varying spacing of the vanes and thus the varying fraction of the annular passage available for the flow of the steam.

Within these elements wide variations may occur, thus offering means for any desired adjustment of the law of flow, and of the relation between the two parallel transformations of energy which the process is designed to effect. It is obvious that in this mode of operation the velocity of flow will be much less than in the simple type illustrated by the De Laval, and therefore that lower rotative speeds may be used. This fact makes possible also the construction of the turbine in as large units as may be desired, and thus places the mechanism, as a prime mover for propulsive purposes, immediately at the service of the marine engineer.

In the Curtis type the operation is more distinctly step-wise than in the Parsons type. Transformation (1) is effected by a series of

sets of nozzles, each set operating through a moderate pressure difference and thus developing a corresponding part of the total developable jet energy. Transformation (2) is then effected in steps alternately with those of Transformation (1) by allowing the steam to act on a series of two to four rings of moving vanes, alternate stationary vanes on the casing serving to redirect continually the jet in the proper direction for each successive set of rotor vanes. Between each of the steps of Transformation (1), therefore, Transformation (2) is effected, also step-wise, and thus the entire process goes forward. Here, likewise, there may be provision for some expansion during Transformation (2), and thus for an action similar to that in the Parsons type. The size, shape and distribution of the nozzles may also be adjusted so as to give such a division of Transformation (1) among the various steps as may be desired.

In this type of turbine, likewise, the velocities developed are relatively moderate, and therefore it becomes available for marine propulsive purposes, as represented by the propulsive machinery of the yacht *Revolution,* noted previously.

The Rateau turbine is a type quite similar to the Curtis, except that between each step of Transformation (1) only a single ring of vanes is introduced for effecting the corresponding part of Transformation (2). The machine thus consists of a series of single ring elements for the steps of Transformation (2) alternating with appropriate nozzles for the steps of Transformation (1). This type has shown good results in France, and is represented by installations of propulsive machinery on two torpedo boats of the French Navy.

In the Riedler-Stumpf turbine a generally similar arrangement is used, the chief difference being the use of a "Pelton" vane milled into the periphery of the rotor, and thus adjusted for a tangential rather than for an oblique direction of jet, as with those in which the vanes stand radially.

The more important advantages and disadvantages of this type of prime mover, or, rather, its various points of individuality, some of which may prove to be advantageous and some disadvantageous for the general purpose of ship propulsion, must now be reviewed for marine purposes.

Weight.—In the installations thus far made there has been considerable weight saving, as compared with reciprocating engines of

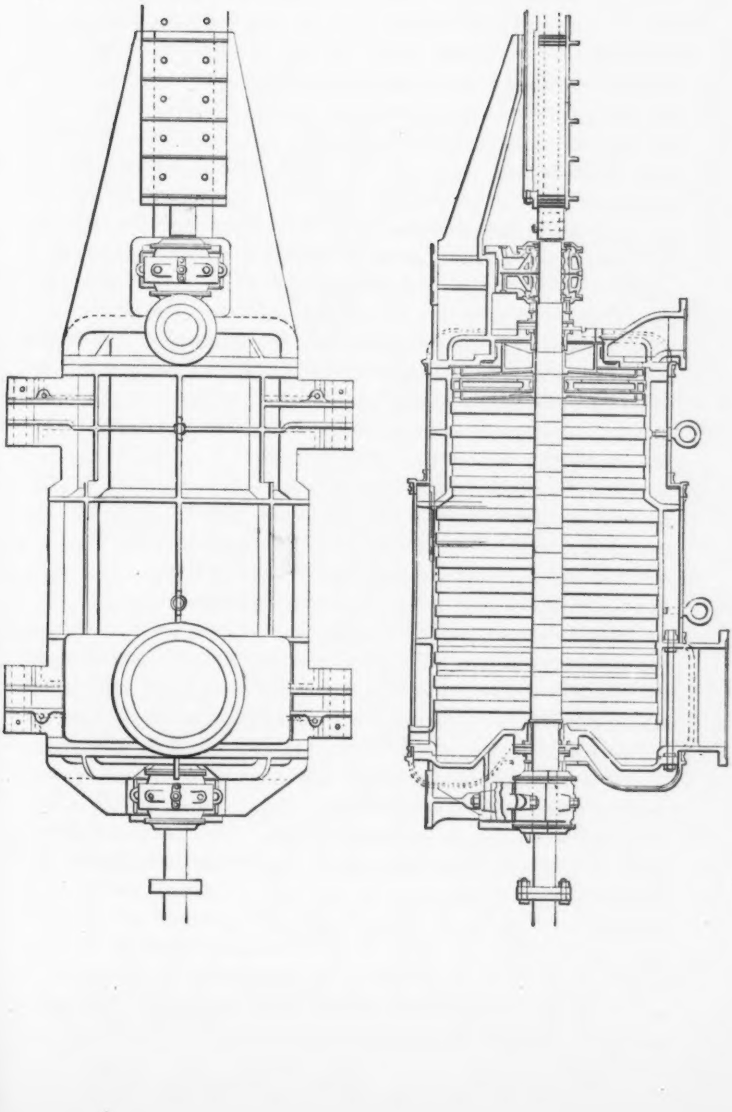

Fig. 5.

the same capacity. According to the reports of the Cunard Commission, however, regarding the use of the turbine on the new ships of that company, as referred to, the saving in an entire installation of some 75 000 h. p. will be only some 300 tons, an amount so small that any slight change in the schedule of design might wipe it out altogether, or even change it to the other side of the account. This result is surprising, in view of the apparently well-assured saving in smaller installations, but may arise, at least in part, from the much lower rotative speed of about 140 rev. per min. proposed for these turbines, as compared with speeds of 600 to 1 200 rev. per min. in most of the present actual cases. On this point further experience is needed, to give assurance as to the status of the turbine, but when the short time during which it has been under consideration as a marine motor is remembered, and the fact that most of the effort thus far expended has had relation to qualities other than lightness of construction, it may well be believed that future designs will show advances in this direction, and that, in any event, in comparison with present practice, future designs of turbine machinery will show a saving in weight.

In so far as such a saving may be effected, speed or carrying capacity may be increased, and the use of this motor, as far as it may permit of a saving of weight without at the same time involving any sensible loss in propulsive efficiency, becomes, therefore, an important factor in the development of advancing speeds.

Space Occupied and Location of Machinery.—The space required for turbine machinery will depend at present much on the type used. The Parsons design tends toward small diameter and great length, and in this form will be expensive in fore-and-aft space, but economical in vertical space. Such a type, therefore, might be better suited for a transatlantic liner than for a warship, or even a freight steamer, where length of space in the hold is an item of relatively greater importance. On the other hand, turbines of the Curtis and Rateau types tend to larger diameters and shorter lengths, as compared with the Parsons, and, therefore, in this particular seem to be better adapted to the general purposes of marine propulsion. It is not unlikely that all these may be found to be transition types, and that, with experience, some modified form will appear with some combination of the good qualities of prevailing types, and with special adaptation to the demands of marine propulsion.

The center of gravity of the turbine is low, and, as far as location is concerned, this fact, therefore, will tend toward increase of stability, or may permit of the raising of other weights for the determination of any desired metacentric height or range of stability specified.

The same fact will also favor the protection of turbine machinery on warships, and will react advantageously in this respect on various features of warship design and construction.

Rotative Speeds.—For the best efficiency, the turbine tends toward high rotative speeds; higher often than the screw propeller will admit for its own best efficiency under the conditions imposed by the design. A compromise, therefore, must often be effected between the conditions best adapted to the propeller and those best adapted to the turbine. In particular, it may result that some part of the available efficiency of the propeller must be sacrificed in order to obtain the best combination result, and in such case a high rotative speed of the turbine must be reckoned as a relative disadvantage. It must be remembered particularly that the ultimate test of propulsive efficiency lies in the power transformed into the direct propulsion of the ship, and that the top-notch efficiency of the turbine may be rendered of small avail by a propeller operating under inefficient conditions.

As the problem of the combination of the propeller and the turbine are further studied, however, it may confidently be expected that a basis of agreement may be reached which will involve no serious loss of efficiency on the part of either, and that the relatively high speeds of rotation will no longer be considered as involving, to any serious degree, a loss of propulsive efficiency. Under this head, remark may also be made of the tendency to discard multiple screws on the same shaft which were used in early installations, and particularly in the *Turbinia,* where three shafts, each carrying three propellers, were used. Later, in such installations, two propellers were installed on each shaft, while in most of the latest designs but one propeller on each shaft is shown, the rotative speeds being brought down to a point permitting a sufficient diameter for the propeller area needed, without resort to the multiple system.

Balance.—The mechanical construction of the turbine is of the

utmost simplicity in type, showing only a single symmetrical rotating piece as its moving part. This is perfectly balanced dynamically and statically, and there are, therefore, no inertia forces whatever arising from reciprocating parts as in the ordinary type of marine engine. The only agency which may give rise to ship vibrations with turbine machinery seems to be at the propeller, which, if out of balance, or if exposed to varying resistance during the rotation of the blades, may produce corresponding disturbances at the stern of the boat. Experience has shown, however, that, with turbine machinery, ship vibrations become a negligible quantity, and this type of motor may, therefore, be counted upon for the practical elimination of this troublesome problem in present-day practice with reciprocating engines.

Backing and Maneuvering.—The turbine cannot be reversed after the manner of the reciprocating engine, and for this reason special provision must be made in marine installations for running the shaft in the backing direction. The accepted method in present installations involves the provision of a section of the turbine rotor furnished with one or more rings of vanes set in the inverse direction, and provided with appropriate connections for separate steam supply. This section is usually located at the exhaust end of the turbine so that when going ahead it is operating in a partial vacuum, and is, therefore, absorbing the minimum amount of power in overcoming vapor friction. This feature, apparently, must count as a relative disadvantage of the turbine, since, in order to back, this extra section of turbine must be provided, constituting, when going ahead, a useless weight, and absorbing at least some power in overcoming the frictional resistance of the medium in which it revolves. In the earliest designs but a small fraction of the go-ahead power was provided for backing. In later designs this fraction has continually risen to values of about one-half or more. No effort is made, however, toward special economy in the backing section, and, therefore, such a fraction of the go-ahead power may be developed without by any means requiring a corresponding fraction of the weight.

Economy.—Regarding the economy of the steam turbine for propulsive purposes, there seems to be some uncertainty at the present time. This in part arises from the difficulty of measuring

or knowing the power which is developed in any given case. The steam turbine cannot be indicated after the manner of the reciprocating engine, and therefore there is no way of knowing the power developed, except by inference from the propulsive performance. For stationary-power purposes, and particularly for the operation of electrical generators, where the power delivered may be measured by the electrical output and the known efficiency of the generator, this uncertainty is removed and the economic performance may be definitely known. For marine purposes, however, the efficiency of the propeller enters as a factor into the judgment regarding economy, and it may well be that in some cases the efficiency of the turbine has suffered by this reason. Judged in this manner, either by direct inference from the propulsive performance, or by comparison with the coal economy of similar steamers with reciprocating engines and a known indicated horse-power, the performance in the case of the Clyde turbine steamers has been reported as highly satisfactory and as indicating some saving over those of similar type with reciprocating engines. Regarding the English Channel steamers, the information is less definite, and regarding the torpedo boats or destroyers which have thus far been equipped with this type of propulsive machinery, the evidence is likewise somewhat variable. In some reported trials the economic results seem to have been satisfactory, while in others they indicate a lower efficiency than might be expected from reciprocating engines, in some cases the estimate of power indicating a coal consumption of considerably more than 2 lb. per h. p. per hour.

Accepting the figures given by tests with electrical machinery, it may be considered as demonstrated that, with ordinary saturated steam, such as is furnished by boilers without superheaters, the steam turbine in itself shows an economy of practically the same order as the reciprocating engine under like conditions. With superheated steam, however, the turbine seems to show a pronounced advantage and a distinct gain in economy. The two conditions which seem to influence peculiarly the economy of the steam turbine are quality of steam and terminal pressure. The turbine is especially sensitive to these two conditions, and shows marked gain in economy with increase in superheat and decrease in terminal pressure. Aside from the better thermodynamic conditions which

these changes imply, it is believed that a considerable part of the gain is due to the reduction of the friction of the rotor due on the one hand to the decrease or absence of water of condensation from adiabatic expansion, and on the other to a decrease in the density of the vapor at the exhaust end where are found the highest peripheral speeds and largest vanes, and where vapor friction will cause the greatest loss.

The reciprocating engine, in economy, is sensitive to both increase in initial pressure and decrease in terminal pressure, and it is found that pressures, at least up to 200 lb. or more, are required for the highest contemporary efficiencies. With the turbine this does not seem to follow, and of the two there seems to be more gain relatively by a decrease in the terminal, than by an increase in the initial pressure. Due to this fact it may be considered that for the same economy the steam turbine does not call for as high an initial steam pressure as the reciprocating engine, while it does call for a distinctly lower terminal pressure and better condenser vacuum. In the best turbine practice at present a vacuum of about 28 in. is considered as standard, and as required for the development of significant turbine economy.

Due to the fact, furthermore, that there is no cyclical history of the steam, the walls of the rotor and casing reach a steady condition as regards temperature, and therefore there is no periodic transfer of heat from the steam to the walls and from the latter to the condenser, thus resulting in serious loss by initial condensation, as in the reciprocating engine. Due to the same fact, there is no limitation in the economical expansion ratio, as in the reciprocating engine, and with turbines the steam may and should be expanded to an extent far exceeding ranges which have hitherto been customary. In turbine practice, expansion ratios may reach to a hundred-fold or more, and in fact, such high ratios are demanded for the best results, and as a condition of the low terminal pressures previously referred to.

These various conditions for economy with the turbine require large connections on the exhaust end, large condensers, and especially careful workmanship and supervision with regard to both condensers and air-pumps. In this respect, relatively, the turbine is at a disadvantage with the common type of engine.

Another point wherein the turbine suffers somewhat by comparison with the reciprocating type of engine is in the range of economy. From the nature of the turbine, the power cannot be varied by changing the point of cut-off and thus varying the expansion ratio. Such variation of power as is required is usually brought about by controlling in one way or another the quantity of steam which is admitted into the turbine. Thus, where multiple nozzles are used, as in the Curtis and Rateau types, the number of nozzles opened may be varied and the steam inflow controlled in this manner. Where such nozzles are not used, as in the Parsons type, the steam inflow is controlled by a poppet or special form of valve to which is given an intermittent motion in accordance with the demand for power, thus permitting the steam to enter in a more or less interrupted series of puffs for reduced rates of power output, varying up to continuous flow for full power.

Under these conditions it is found that the economy of the turbine increases continuously with its output, and does not, as with the reciprocating engine, find a range of minimum steam consumption on either side of which the consumption increases.

The economy of the turbine is furthermore sensitively dependent on the speed of rotation. If the speed can be maintained at or near its maximum and the resistance alone varied, as, for instance, in the operation of an electric generator, a relatively wide range of power may be covered with a slight falling off in economy. In marine propulsion, however, speed and resistance necessarily vary together, and decrease in speed of ship carries with it decrease in rotative speed, as well as decrease in power. Due to these facts the economy of the turbine falls off rapidly with reduced speed, and its general operative efficiency, therefore, is only satisfactory for conditions close to the maximum for which it was designed. As noted previously, there seems to be no way, with such type of motor, of paralleling the reduction of power in the reciprocating engine by earlier cut-off, increased number of expansions and decreased mean effective pressure. This limitation in speed variation, with small change in economy, must count, therefore, for the present, as a disadvantage for the turbine.

Combinations have been proposed of turbines and reciprocating engines, the former, or both together, for full power ahead, and the latter for reduced speeds, and to aid in backing. Such combinations,

at best, are expensive in space occupied, and it is by no means sure how satisfactorily they would meet the general requirements of the case. The idea remains simply as a proposition, and without demonstration by actual trial.

For these general reasons regarding range in economy, the turbine is, perhaps, in this particular, less well adapted for warship practice, where most of the power is developed at lower rates of output for cruising purposes, than for mercantile use, where, as a rule, the power is developed at full rates of output, and hence under conditions most favorable for economy.

The more general adoption of the steam turbine for marine purposes, and its future as a marine prime mover, must depend on two main facts; first, its adaptation mechanically to the operation of a screw propeller; and, second, the resultant economy of operation.

Regarding the first point, as already noted in the discussion of its various characteristics, the evidence seems to be sufficiently conclusive in favor of the turbine.

Regarding the second point, the evidence of superiority over the reciprocating engine is less conclusive. As already pointed out, the question of economy is more than a problem of thermodynamic efficiency; it is a problem of propulsive efficiency as well, and, with present knowledge, engineers are much in the dark regarding the interpretation of the total result, and as to whether the relatively large coal consumption in certain cases is to be charged to the propellers, or to the turbine, or to both. While the evidence now in hand shows a general economic performance of the same order for the turbine as for the reciprocating engine, and while one may look to the future with confidence that the general problem of economy will be solved satisfactorily, and while the extent to which the turbine has already been installed, or is contemplated in present designs, may be taken as evidence of the confidence felt in regard to this matter, yet it must be admitted that the exact status of the turbine in regard to general resultant propulsive economy is still in abeyance, and must remain for further experience to determine.

The Internal Combustion Motor.

As forming a part of the general advance in matters relating to marine engineering, mention should be made of the internal com-

bustion motor, typified by the gasoline engine, and forming so important a feature in connection with the design of small pleasure launches and special-purpose craft of various kinds.

The internal combustion motor differs from the combination of steam engine and boiler in the union of the two operations of combustion and expansion operation in one mechanism. With coal and steam the heat energy is liberated in one place, and transformed into mechanical work in another. With the combustion motor, the heat energy is liberated and transformed into mechanical work in the cylinder of the motor, and as successive events of a continuous cycle.

In such an outfit, therefore, there is no coal or boiler, and the attendant heat and discomfort are removed. This feature, as well as the saving of space, is of special value for small boats, particularly for pleasure purposes. The design and construction of such boats, mostly in sizes from 20 to 40 ft. in length, and equipped with motors of 3 to 10 h. p. has taken on during the past few years an enormous expansion, and has come to be a standard feature of the engineering practice of the day, for pleasure and other special purposes which such boats may properly fill.

In later designs in this field, special attention has been paid to weight, and in a certain class, coming to be known as auto-boats, the relation of weight to power developed has been reduced to very low figures. This favors the attainment of high speeds, and just at the present time the development of boats of this type for the highest attainable speeds is attracting much attention from designers and builders of pleasure craft. In recent cases 1 h. p. is developed on 25 to 30 lb. total machinery weight, and is installed on about 15 to 20 lb. of boat weight, thus giving 1 h. p. for 40 to 50 lb. of displacement weight, or at the rate of 40 to 50 h. p. per ton of displacement. With boats of this type, and in lengths of 30 to 50 ft., speeds of 20 to 25 miles per hour are obtained, and there is every indication of a rapid development along these lines and of the construction of still larger boats of this type, and of the attainment of correspondingly higher speeds.

The internal combustion motor, however, in its present form and mode of operation is by no means a finality. Motors of this type require a delicate adjustment among the various attendant con-

ditions, and leave much to be desired on the score of reliability and certainty of operation, especially in starting and in the control of speed variation. It will remain for the future to develop and provide improved conditions in these respects.

In economy, internal combustion motors give a higher thermodynamic efficiency than most steam engines, and a correspondingly low rate of fuel consumption. Due, however, to the specialized character of the fuel used, the cost per horse-power with gasoline motors is naturally greater than with steam. For the special purposes to which such boats are put, however, the increase in operating expense, due to this fact, is usually of small relative importance.

Interesting results have also been obtained recently with special forms of producer gas outfits of the suction type, and intended for coal, coke or other kinds of solid fuel. With high-grade fuel, reports indicate the development of 1 i. h. p. per hour with a combustion of about 1 lb., and the general indications regarding such outfits give hope of usefulness in certain parts of the general field of marine service.

There does not seem to be any present likelihood, however, of the general displacement of the steam engine by the internal combustion motor, and this is due primarily to two causes: (1) Mechanical and practical difficulties which lie in the way of constructing and operating such motors of large size; and (2) the greater cost of fuel or greater bulk and weight of apparatus required.

Within its own field, however, the internal combustion motor boat forms one of the most interesting developments of the past decade, and marked improvements may be looked for in the near future, and, presumably, a corresponding increase in the extent of field occupied and in the importance of such forms of motor for the purposes of marine propulsion.

Propulsion.

During the past ten years there has been but little definite progress in matters relating to the propulsion of ships. The screw propeller still holds the field as the typical means for marine propulsion, and has invaded to a considerable extent the field of river and general shallow-water navigation, long the especial field of the paddle-wheel.

As is natural from its extreme importance, the screw propeller during the decade has been the object of continued study, both theoretical and experimental. There has been no marked advance, however, in the theory of its action, nor is there likely to be without further development of the experimental foundation on which any practical theory must rest. There has been a gradual accumulation of experimental data, however, particularly in the experimental canal at Cornell University under a grant from the Carnegie Institution at Washington, and an extended investigation has been in progress in relation to the general performance of standard forms, which, when completed, should furnish valuable indications regarding the influence on the performance due to the three main factors, pitch ratio, slip and surface.

The fundamental features of the theory of the screw propeller are well known, and further advances having relation to its design or adaptation to special problems require more facts rather than more theory, valuable as the latter may be for purposes of general investigation.

On the whole, however, both pure and applied theories of the screw propeller may be considered as fairly well in hand, and it is likely that in most cases the preventable margin of loss due to the propeller alone is not serious. It seems well established that the highest attainable efficiencies for the screw propeller are close to 70%, and it is not likely that any amount of research or experience will point the way to a value of efficiency higher than this in any marked degree. The purpose of further investigation and study is not so much the development of a design with higher maximum efficiency, but rather such an understanding of the conditions affecting efficiency that average operating values may be raised, and in any given case a value, closely approximating the maximum, may be safely counted on.

Mention may be here made of a special condition which arose, during the past decade, in connection with the operation of small propellers at very high speeds, and under conditions which threw upon them a large amount of power and a high value of the propulsive thrust.

These conditions, especially as met with on the first turbine boat *Turbinia* and on certain designs of the torpedo-boat class, gave rise

to the formation of partial cavities about the following edges or surfaces of the propeller blades, with a resulting lack of water operated on and thrust developed. This phenomenon, known as cavitation, has formed the subject of extended examination by both Barnaby and Parsons, who have related it to the thrust developed per square inch of projected propeller area, and find that while it is doubtless primarily dependent on speed of blade, depth of immersion and slip under which it is operating, yet, for practical purposes, the limiting condition may be most readily expressed in terms of thrust per square inch of projected propeller area, and state that available experience points to the limit of about 11 lb. per sq. in. as insuring safety with regard to this condition.

For combination with turbine machinery, or with high-speed gasoline engines, as in the so-called auto-boat, or in other cases of special design, peculiar interest attaches to the performance of screw propellers of unusually low pitch ratio. In standard practice, the ratio of pitch to diameter has rarely fallen much below 1, and values of 1 to 1.4 have covered the range of general design. In some cases of recent special design, however, values of the pitch ratio down to 0.5 and below have been contemplated, and at the present time, the general performance of such propellers forms a question of much interest and importance, especially with reference to the best combination of steam turbine and screw propeller for the purposes of marine propulsion.

An allied question has reference to the best available efficiency with more than one propeller on the same shaft, and the conditions needful for the realization of such efficiencies.

In the early days of turbine propulsion, as has been already noted, three propellers, and later two, were used on one shaft, while in present practice but one is used. The primary purpose of multiple propellers has been to reduce the thrust per square inch of projected area, and thus to avoid conditions likely to produce cavitation and its attendant loss as previously noted. Although in later designs it is believed that these conditions have been met with a single propeller, it is by no means unlikely that conditions may arise under which multiple propellers on one shaft will become a necessity, and, if so, the conditions for the best possible efficiency become a matter of much importance. In addition to the items

which influence the performance of a single propeller, such a problem will also involve the distance between the propellers, their relative surfaces and their relative pitch ratios. In particular, while it is difficult with present data to specify the proper relation between the pitch ratios of two or three propellers on one shaft, it seems to be very certain that they should not be the same, and that much of the success or failure of the combination might be due to the selection of a proper combination in respect to this feature.

Future experience must answer special problems of this character. The past decade has done its part in assuring general advancement in the knowledge of the screw propeller, in the better determination of the conditions for best efficiency, and in the presentation of new problems bearing on the further development of marine propulsion. It seems likely that no revolutionary changes in this part of the field are to be anticipated, and that the progress of the future in this direction must consist chiefly in the further study of special conditions, and in the still more reliable determination of the limiting conditions for specified individual cases.

Auxiliary Machinery.

Regarding the use of auxiliary machinery in marine engineering, there are few items requiring special mention in a chronicle of progress covering the last decade. Electricity has steadily advanced in the variety of its applications, and is now used almost universally for lighting, and, to some extent, for heating. Electric power is used for operating fans, both for ventilation and forced draft, winches and cargo hoists of all kinds, and on warships for ammunition hoists and for the turret-controlling gear. It is also used to some extent for the operation of centrifugal pumps, and, in some few instances, for refrigerating machinery. Under these circumstances, the electric generators, motors and other appliances used on shipboard have assumed a position of serious importance, and require careful attention in both design, construction and installation.

Thus far, electric installations on shipboard have been of the direct-current type, the peculiar advantages of alternate-current generation for long-distance distribution not being significant for the distances involved, and the readier adaptation of the direct current for power purposes proving a determining feature. With the later

development of alternate-current motors and their adaptation to almost all possible power purposes, however, the special advantages of the direct-current distribution on shipboard are becoming less significant, and with the resources at the disposal of the electrical engineer of the present day, there seems to be no serious reason why, if desired, the various requirements on shipboard might not be met by electric machinery of the alternate-current type.

Generators are usually operated by small direct-connected steam engines, though latterly the steam turbine has come into some favor for such purposes.

With increased size of units and general increase in the attention given to matters affecting economy, there has been a steady improvement in the cost of electric power in terms of coal burned. At best, however, engines of the type and size commonly used for such purposes are wasteful of heat, and rarely give 1 h. p. per hour on less than 30 to 40 lb. of steam, or 3 to 4 lb. of coal. In large units, however, and with compound engines running on full loads fairly steady, these figures may be reduced to the neighborhood of 20 to 25 lb. of steam, or 2 to 3 lb. of coal.

During the past decade great improvements have been made in the details of electric installation on shipboard, and at present all leading ship registration societies give extended rules for the proper installation of all electric machinery, including generators, motors, wiring, lamps, signal apparatus, etc. The reduction of the varied practice of the early installations to the standard practice of the present day, based on the experience of the past twenty years, has done much to insure the safety and reliability of all apparatus of this character.

Regarding the various pumps used on shipboard, the practice and status during the decade have remained substantially constant. The most important advances have been in the direction of greater economy, especially for the air and feed-pumps. Such pumps of the direct-acting type are notoriously inefficient in steam economy, and records of steam consumption for ordinary types operated without due regard to conditions for economy show results ranging from 100 lb., or somewhat less as a minimum, to 200 or 300 lb. or more per h. p. per hour. With special effort toward economy, however, both in the design of the pump and in the mode of operation,

the steam consumption has been brought down to the neighborhood of 40 lb. and upward per h. p. per hour.

In the design of air-pumps, steady advance has been made in the decrease of weight and increase in economy, with substantial uniformity of type. For high-speed engines, the "Bailey" type of direct-connected air-pump has met with high favor. In this pump the plunger acts as its own valve, and, therefore, the use of valves operated by the residual pressure in the condenser is avoided. For high speed of operation, as with direct-connected pumps on torpedo boats and similar small craft, such a type of pump has given excellent satisfaction, and has found a definite place in the practice of the day.

In condensers, the type has remained without important change, and progress has concerned itself chiefly with minor or structural details, especially such as may relate to the saving of weight and space occupied. The most serious difficulty in connection with the modern condenser is in the deterioration of the tubes, and the present great desideratum is for a material which will withstand the corroding influences to which condenser tubes are subject, and which will not be too expensive as compared with the brass alloys at present in use. The need for such a material has been clearly developed during the past decade, and it is hoped that well-directed research during the next decade will provide the remedy.

For circulating pumps, the centrifugal type, direct-driven by a small steam engine or electric motor, is the standard; a type well established ten years ago, and the status of which the experience of the decade has still more definitely confirmed as the best adapted for the particular service demanded.

Such pumps are usually provided with a double inlet, one from the sea and the other from the bilge, so that by proper adjustment they may be made to serve as bilge pumps in case of need.

The use of refrigerating machinery has become more general on shipboard during the decade, and in the details of installation and operation great improvements have been made. Both compressed-air and volatile-liquid systems are in use. In the former case the Allen dense-air machine represents standard American practice, while in the latter, standard types of ammonia machines are generally used. The utilization of refrigerating machinery in large

units on refrigerating ships for the handling of perishable foodstuffs such as meat and fruits, has undergone extended development during the past decade, and the installation of such machinery has received notice from the leading ship registration societies, and is covered by appropriate rules in the same manner as for the electrical equipment, or the main propelling machinery itself.

The use of centrifugal fans for ventilation and mechanical-draft purposes is to-day still more strongly intrenched in marine practice than was the case a decade ago. There has been a growing recognition of the need of separate installations of fans for ventilation and mechanical draft, and in the best practice of the day the same fan is not commonly called upon for more than one purpose. In particular, of course, is this the case with the induced system of draft. Fans have been operated for the most part by direct-connected steam engines. Latterly, as already noted, electric motors have come into some use for operating ventilating fans, but have not been considered as suitable for the conditions under which mechanical-draft fans must operate. The steam turbine in small sizes is now attracting some attention for this purpose, and, according to report, has given fair satisfaction in trial installations.

In auxiliaries having relation to the boilers, the increasing use of the evaporator or special distiller for make-up feed-water is, perhaps, of greatest significance. The past decade has witnessed full acceptance of the principle of operation, that no marine boiler, whether fire-tube or water-tube, should be fed with salt water, and that special provision, usually by evaporator, should be made for the margin of loss which always occurs in the operation of marine machinery. This places the evaporator, already in favor at the beginning of the past decade, on a definitely established status, and marks it as a standard item of the best practice of the present day.

The use of the feed heater in one form or another has also increased in marked degree during the period under consideration. This is simply an item in the general advance along all lines bearing on economy. Heaters, both of the open and closed type, are used, and steam for supplying the heat is taken from the various receivers, from the various auxiliary exhausts, or even as live steam from the boiler, and in various combinations, according to the details of the case and the ideas of the designer or engineer in charge.

The items of such combinations are of less importance, for the present purpose, than the recognition of the extent to which the demand for better economy has come to be recognized and accepted as a guiding principle in the design and installation of all forms of marine machinery.

Perhaps more clearly than ever before, the various causes and ways of heat loss are coming to be recognized. The marine engineer of the present day sees more clearly than he did a decade ago heat streaming away in the condensing water, in all exhausts not returned to a condenser, through the escape-pipe whenever the safety valve lifts, by way of the whistle whenever it is blown, through innumerable steam and hot-water leaks, continually by radiation to the air and by conduction to the ship and thence to the ocean, by way of the funnel in the heat of the waste gases, in unconsumed carbon and hydro-carbon gases, by way of the ash-chute in unconsumed coal, at every bearing and rubbing surface in friction, and, in general, at every transformation or modification in the energy which it is his province to develop and utilize for the propulsion of his ship.

The recognition of these causes of heat loss, and the ever more insistent demand for better economy which has been formulated during the past decade, have been potent causes for much of the improvement in detail in marine design and installation, both in main propelling machinery and in the auxiliary equipment.

Taking the field of marine engineering at large, the key-note to much of the progress during the past decade has been economy. The general demand for more in the way of achievement, larger size, higher speed, greater comfort and safety, is, indeed, but an expression of the spirit of the age, and has been paralleled in all other branches of activity; but, in addition to the demand for more in quantity, there has also been an insistent demand that this shall all be provided with the minimum investment in terms of space, weight and energy. This, again, represents no less distinctively the spirit of the age, and the demands for more and at relatively lower expense give the key to the chief lines of progress during the past decade, and point the way of the lines of future effort most likely to be fruitful, and to accord with the present spirit of human progress.

TRANSACTIONS

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MARINE ENGINEERING.

IN FRANCE.

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Translated from the French

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This paper is a *résumé* of the improvements made in France during the last few years in the construction of marine engines and boilers, and does not go back farther than 1889, that is to the time of the Paris Universal Exposition.††

It is not the writer's intention to treat of the most recent innovation in the motive power used in ship designing, that is the steam turbine, nor of other recent internal combustion motors which, confined until recently to pleasure craft, are now being used in larger and more important vessels.

Nevertheless, the writer's work covers rather a large field for the reason that, while steam engines, which had attained a high degree of perfection, have not been, in these last ten years, the subject of

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†† M. Daymard, in an earlier paper, has stated the improvements made in marine engineering from 1850 to 1889.

important and startling changes, still they have been improved in several details, the sum of which constitutes a decided improvement. The same remark applies to boilers.

The necessity, during the last fifteen years, of increasing the speed of warships and great liners has compelled naval constructors to solve problems which become more difficult every day, with a view to reducing the weight and bulk of the machinery and, at the same time, the cost of fuel.

As triple and quadruple-expansion engines were already in use and were giving good results with a normal pressure of 9 to 10 kg., the only possible improvement was to adopt a higher initial pressure with a larger expansion. As to the weight of, and space occupied by the machinery, the improvement must necessarily have, as a consequence, an increase of the piston speed of the engines, a greater consumption of coal for the boilers and, for both, the use of stronger and more resistant materials.

The principal improvements of details which have permitted, in a large measure, the realization of these desiderata will be reviewed.

Engines.

Engines may be divided into three principal classes:

First.—High-duty engines of great liners and large warships;

Second.—Engines of steamers belonging to the cargo-boat type, or freighters;

Third.—Engines of torpedo-boats, destroyers and small packets, or mailboats, designed for short but very fast trips.

High-Duty Engines.—One of the first consequences of the necessity of taking up less space and of decreasing the weight was the adoption of vertical engines on men-of-war. Until a few years ago, and in spite of the irregular wearing of the several pieces, naval constructors favored the horizontal engines, owing to the ease with which the machinery could be installed under the protected deck, giving, at the same time, a comparatively long stroke.

On the other hand, vertical engines had been used on merchant vessels for a long time, and the experience so obtained resulted in several improvements which were applied to great liners and men-of-war. In the latter, however, the strokes had to be much shorter

than in the former, but greater revolution speeds were attained, and, on both types, piston speeds reached and even went beyond 5.10 m. per second. Owing to improvements in either the friction surfaces, the proportions, the grade of materials, or in the care with which the lubricating parts were designed, this increase of speed or of displacement of movable parts did not entail any diminution of safety, or any decrease of the economical output of the machinery.

To the decrease of weight obtained by the speed of the piston, was added, in a large proportion, the decrease due to the substitution of cast steel for cast iron, not only in stationary pieces, but also in certain movable parts, such as the pistons.

French foundries and mills endeavored to manufacture in the best possible condition and with the minimum sections and sizes allowed by careful calculations, all the large pieces, such as foundation bed-plates, frames, platforms, etc. This was not done without difficulty, and great care was exercised in the design of complicated castings in order to avoid cracks and, at the same time, to facilitate the cooling and contraction of the metal. Cylinder heads and even high-pressure cylinders were made of cast steel, but these latter are still few in number, owing to the cost and rehandling necessary to correct defects and flaws.

In the construction of pistons, steel has superseded cast iron without any difficulty. The old double-wall, cast-iron piston has entirely disappeared and has been replaced by the wrought or cast-steel piston with single wall, and conical in shape. There is also a tendency to make all movable pieces of tempered, medium, or even hard steel, such as nickel steel, instead of soft steel.

However, in reducing these pieces within the limits permitted by the use of a more resistant material, care had to be taken in order to avoid dangerous elastic deformations. One great result was the possibility of considerably reducing the brittleness of pieces usually made of soft steel.

The adoption of hollow shafts has also been the means of a reduction in weight. All the improvements made in the manufacture of cast or wrought-steel pieces are due to the efforts of French steel and iron manufacturers and, among the foremost, to Schneider and Company's Creuzot works, to the Aciéries de la Marine of St. Chamond and to the Firminy Forges.

In spite of doubling up the low-pressure cylinders, and the adoption of two and even three shafts, the increase in the size and bulk of the machinery has been such that it has become necessary to change the system of slide valves.

On all warships and almost all fast liners, the old slide valve, with its causes of deformation and wear, has been replaced by the piston valve, naturally balanced and more easily taken apart. It has, however, the disadvantage of requiring more space, but naval constructors, after studying the different organic parts and the piping, have succeeded in locating the piston valves, even the low-pressure ones, without increasing the length of the engine rooms, and in reducing all lost spaces and voids in the same proportion as was obtained with ordinary slide valves.

It was also sought to balance the weight of the piston valves by using discs of different diameters so that the pressure would tend to push the valve, and that the only resistance to be overcome would be that due to friction and inertia.

Control of the steam valves has been obtained by various developments of the Stephenson link and also by a system using only one eccentric. After some experiments, it was found possible to control the steam valve by a single articulated rod, doing away with intermediate transmission parts which were only complications and causes of danger and breakdowns.

The link with its two eccentrics is used principally when the engine rooms are long and narrow and the steam valves located between the cylinders, as is the case in liners. The rod with but one eccentric is preferred when the valves are on one side, as is the case on several warships.

The rise in temperature, due to ever increasing pressures, as well as precise designing required by greater piston speeds, have led to the study of the general framing of engines and the precautions necessary in view of expansion.

Heated pieces must be free to expand and dilate without displacing their axes, so that such displacements could not be sufficiently corrected by reverse deformations. On all large engines, the cylinders are kept independent of each other and each is connected to the frames. Often the frames carry a rigid platform made of rolled or cast steel on which the cylinders are connected. This

constitutes the upper chord of a beam or truss having a very great moment of inertia, and of which the columns or frames make the web and the bed-plate the lower chord.

The cylinders are connected by bolts passing through oval holes, permitting a slight motion for expansion. Sliding keys, made fast in the connecting flanges and crossing each other along the geometrical axis of each cylinder, guide the displacement, so that the position of this axis remains fixed.

Moreover, the cylinders are connected in pairs by ties placed transversely to the axes in order that the expansion may take place on either side of the fastenings.

The increase in the number of piston strokes and in the actual weight of movable parts has increased the forces of inertia of the moving masses, and has led to great accuracy in the calculation of these forces, in order that they may be considered in the design of the pieces, as well as in determining the vibrations which may originate in the machinery itself and be transmitted to the hull of the ship.

The causes of, and laws governing these vibrations, as well as the means available to resist them, have been the subject of careful theoretical and practical studies. For certain fast transatlantic liners, several solutions were submitted to calculation and experiment by means of small models,* and resulted in adopting on those vessels certain dispositions which have assured to their passengers remarkable conditions of comfort.

Since then the question of balancing the engines has been studied under different phases: the position of the cylinders; the angle of advance of the cranks; the use of counterweights; the equalizing of weights of the various units, etc.

On warships, to avoid vibrations, the engines have usually been located in the center of the ship, upon some very strong keel beams. In a few special cases only, the order of the cylinders has been changed, and the angles of advance made dissymmetrical.

Sometimes the power actuating one shaft was evenly divided between two engines, and soon came the adoption of two shafts and twin-screws. It was in France, the writer believes, on the *Dupuy-de-Lome,* and after experiments made on board *La Carpe,* that the

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* *Bulletin* de l'Association Technique Maritime, 1898.

use of three shafts and triple-screws was first introduced in battleships.*

The distribution of the total power between several engines was done to limit the dimensions of the several parts and the strains to which they were subjected. At the same time, it had a decided influence on decreasing the fatigue of the machinery as well as the vibrations of the ship itself.

On board all large ships, the circulating and air-pumps were detached from the main engine and run by independent motors. The running of the air-pumps was a very delicate question to solve under these conditions, but after patient investigations these engines were perfected so as to run with complete regularity, even without any help from the powerful fly-wheel of the circulating pump. Feed-pumps were also installed independently, usually in the stoke-rooms under the supervision of the chief stoker.

Merchant Vessels Running at Moderate Speed.—After the great liners and powerful warships come the freighters, cargo-boats, or vessels for combined freight and passenger service, sometimes called *demi-paquebots* (half-liners) in France, the speed of which has remained moderate.

The question of weight and bulk being set aside in this instance, it has been possible to retain comparatively reduced piston speeds on such vessels and, therefore, to avoid using costly materials of construction. Under these conditions, the saving in weight for a given power has been only 15 to 20 per cent. But, on the other hand, the aim has been to increase the economical output or capacity by more careful workmanship; by increasing the pressure and expansion; by reheating the air required for combustion and the feed water, etc., and it has been found possible to reduce the fuel consumption to less than 0.49 kg. per i. h. p.

Torpedo-Boats, Destroyers, Small Steamers.—The evolution of engine designing in these ships has been still more pronounced than in the great liners and large warships; the use of highly resistant metals has been more general and higher pressures have been adopted. The weight per horse power (engines, boilers and water)

* It may be said here that as early as 1865 the steamships *Washington* and *Lafayette* were equipped with twin shafts and screws, and, in 1867, in French yards, 3 liners, *Ville de Brest*, *Ville de Nazaire*, *Ville de Bordeaux*, were built with twin-screws, and were very successful as to speed and comfort of passengers,

was in this way reduced to 16 kg., while the fuel consumption dropped to 0.45 kg. per h. p.

This very low consumption seemed at first surprising and led one to doubt the accuracy of the experiments made to that effect; but the same value was obtained so many times and so regularly that it is impossible to question its accuracy. It is due, in part, to special operations, such as the heating of the feed water, and, in part, to the care exercised in studying the distribution of steam. For instance, the sections of all orifices are made quite large. To that effect, the mean and low-pressure cylinders retain the ordinary slide valves which for the same occupied space permit larger passageways, and the maximum outside dimensions of which are small enough not to give rise to the same objections which caused them to be rejected in the large engines.

It is possible thus to run with a very small admission of steam and a high expansion without increasing, beyond reason, the losses due to choking. To avoid the great compressions which are to be feared in the usual distribution system and which produce in the cylinders some dangerously high pressures, automatic safety valves, invented by M. Normand, are used; the steam can then repass from the cylinder into the steam chest as soon as the pressure in the cylinder equals the pressure in the steam chest.

In the engines of smaller vessels, the precautions guarding against vibrations were still more stringent than in larger ones. The equalization of weight of the units was generalized, and it was found advisable to attach the upper part of the engines to the deck above by horizontal ties. Moreover, greater care was exercised in assembling and adjusting the various parts, owing to a decrease of permissible play between them. Small defects which in the past could be overlooked cannot exist in the new engines. That is why these engines, however light and rapid they are, are as safe and have the same endurance as the engines which were in use before their adoption.

Table 3 gives a general idea of the progress realized in different classes of engines, in weight, in space occupied and in fuel consumption.

All these improvements are due to the researches and to the work of several constructors, among whom may be mentioned, MM.

Normand and Company of Havre, the Forges et Chantiers de la Méditerranée, the shops and yards of the Loire and those of the Compagnie Générale Transatlantique (Penhoët). The National Yard of Indret, from which have come several happy innovations, must not be forgotten.

TABLE 3.

		Warships of heavy tonnage.	Fast liners.	Freighters, cargo-boats and mixed passenger freighters.	Torpedo-boats, destroyers, small steamers, etc.
Reduction of coal consumption per horse-power hour.	High duty.	From 1 to 0.740 kg.	From 9.950 to 0.770 kg.	From 0.700 to 0.490 kg.	From 0.775 to 0.650 kg
	Average duty.	From 0.750 to 0.600 kg.			From 0.600 to 0.450 kg.
Reduction of total weight of engines, boilers, water.	High duty.	From 160 to 100 kg.	From 250 to 150 kg.	From 250 to 280 kg.	From 34 to 16 kg.
Reduction of horizontal area per horse power	High duty.	From 0.080 to 0.055 sq. m.	From 0.080 to 0.050 sq. m.	From 0.100 to 0.085 sq. m.	From 0.040 to 0.020 sq. m.
Speed	High duty.	19 to 23 knots.	18 to 22.5 knots.	11 to 12.5 knots.	Torpedo-boats, 21 to 28 knots. Destroyers, 20 to 33 knots.

BOILERS.

During the last fifteen years numerous radical changes and improvements have been made in the manufacture of marine boilers. The characteristic of this evolution has been the almost general adoption of water-tube boilers on warships and their partial introduction in merchantmen.

However, it must be said here that the old type, almost classical for thirty years or so, of cylindrical return flue boilers did not remain stationary, and that is why it has been and is still used in the merchant service.

With better tools at hand, with better workmanship and with the use of steel plates more resistant to shells, these boilers have been so improved that the pressure may be raised to 15 kg. with a diameter of 5 m. without danger of accidents or of leakage, which

were so frequent in the past, even with lower pressures and smaller diameters.

The grates, which are the parts subjected to the most wear, have been improved so that they may be easily renewed, lengthening thereby the life of the boilers and postponing the date of their renewal, an operation always costly.

A forced draft generated in air-tight fire-boxes improves the efficiency, increases the rate of combustion, and, at the same time, is a saving of space and weight.*

In the navy, before the adoption of the water-tube boilers, several tests were made to obtain light and comparatively small boilers, especially in torpedo-boats.

Knowing that the weight per horse power varies nearly inversely as the rate of combustion (weight of coal consumed per hour and per square meter of grate area), boilers, similar to locomotive boilers, giving a very high combustion were first tried. Unfortunately, locomotive boilers, which usually work only for short periods, did not have the required endurance, and the reverse of what was expected did happen.

The changes necessary in this type (shortening of tubes, raising of the fire-boxes, etc.) were so many causes of loss of elasticity and increased the danger of breakdowns and deterioration in severe tests. The forced draft in the air-tight room caused undue strains and fatigue in the tubes when the fire-box was opened. And notwithstanding the fact that some constructors have succeeded in building boilers of the locomotive type running well enough at 300 kg. per hour and per meter of grate, the firing required such care and so many precautions that these results could hardly be considered as practical.

It is in another direction that the solution of this question was found as regards torpedo-boats and destroyers. This problem was solved by the adoption of water-tube boilers known as small tube boilers patterned after the type invented by Captain Temple, the first application of which to torpedo craft was made in 1884 on Torpedo-Boat No. 20.

* As early as 1876, M. Audenet was granted a patent, prior to Mr. Howden's, or at any rate, without knowledge of the work of Howden. But owing to a lack of applications, this idea did not progress rapidly in France.

On the contrary, the Howden system, which besides the forced draft has also a special arrangement for heating the air, was used in several instances and improved with experience, so that, in France, the Howden system has been adopted.

These boilers are much lighter than the locomotive boilers, and, their grate area being relatively greater, the rate of combustion for the same power can be reduced.*

Several trials were made in France and in other countries. The best known are those made by M. Normand, who, while giving all due credit for the success of his first torpedo-boats to Commander Temple's invention, made so many improvements that his name has been justly given to the type of boilers used afterward. The trials made by Torpedo-Boat No. 180 in 1890, by the *Forban* in 1896 and *L'Arbalète* in 1903 show the various stages of the progress made by M. Normand.

M. Guyot, working independently, patented various dispositions somewhat similar to those of M. Normand, and the Société du Temple, with Guyot's patent rights, has also made several improvements of details.

M. Sigaudy, in collaboration with M. Normand, has combined a double-faced battery in a manner very advantageous for high duty.

In these boilers there were two serious obstacles to rapid and efficient combustion: one was the tendency of steam pockets to form in sharp turns and elbows of the tubes, and the poor circulation of the hot gases, due to lack of proper direction.

To overcome these difficulties, the tubes were made as nearly vertical and straight as possible, keeping, of course, the curves necessary for expansion; the inside diameter was increased to about 34 mm., and the thickness to 2½ and even 3 mm. Lastly, it was decided to guide the flames and currents of gas by coils of tubes, so joined as to force them to follow a sinuous path properly traced.

This last arrangement has improved the circulation of hot gases and caused the almost complete absorption of their heat by the series of tubes. This has been still further improved by using polyfaced tubes with which the surface of contact is greater than with ordinary tubes; there is also a better imperviousness to gases, irrespective of the irregularities of the firing.

After changing the shape of the collectors from a rectangle to a

* Let us recall here that it was while experimenting on dirigible airships that Commander Temple, in 1875, built his first boiler, and that his system consists in the automatic circulation of water obtained by exposing to the action of the gases of combustion a series of small tubes (inside diameter, 20 mm.) in which steam is generated, and by placing, outside of the gaseous current, larger tubes through which the water carried to an upper reservoir reverts to other lower reservoirs, to be sent again through the series of tubes and be partly vaporized.

cylinder, care was taken to improve the connections of the tubes to the collectors by making them perfectly water-tight, by improving the method of assembling, connecting and disconnecting.

It is by constant labor and unceasing work that the small water-tube boilers have been improved to the high degree of efficiency which they possess at present, and which allows torpedo-boats and destroyers to attain normally a combustion rate of over 300 kg. with satisfactory results.

In regard to boilers for large ships, the conditions were not quite the same. In this case, very light boilers were not as essential as they were on torpedo-boats, and it was more a question of saving of space that led to the abandonment of the cylindrical return flue boiler, the diameter of which necessarily increasing with the power of the engines could no longer be located under the armored deck of certain cruisers and battleships. For this type was then substituted the cylindrical boiler with direct firing, in which it was sought to save weight by increasing the rate of combustion by a forced draft in an air-tight chamber.

The results were very poor. These boilers, being rather delicate, broke down repeatedly under the action of intense firings, for the same reasons that had attended the unsuccessful introduction of the locomotive boiler in torpedo-boats. Mechanical forced draft was then held responsible for this failure, and, under pressure of this opinion, the Navy Department suddenly abandoned this mechanical draft and adopted water-tube boilers which with a relatively larger grate area permitted a proportionate reduction in the rate of combustion.

It was then found that, with a rate of 150 kg. obtained by a natural draft, it was possible to obtain the same results as with cylindrical boilers running at 300 kg.

Notwithstanding the fears and objections entertained by many regarding water-tube boilers when used as marine boilers, they were installed on every ship in the navy. And this change has been a decided success, since that time, with the exception of some minor accidents, all serious breakdowns having disappeared.

When the Navy Department decided upon this change, the number of water-tube boilers used on the fleet was very small.

Belleville Boilers.—These boilers, the first adopted, had been in

service some forty years. They had been tried on several small and average-sized boats. They were satisfactory as to weight and easily put under pressure, but, in constant use, they developed several defects in regard to feeding, circulation, leaks and wearing of the tubes and collectors. Always undaunted, M. Belleville found a solution to each difficulty; he invented some automatic regulators, feed-water purifiers, expansion traps, etc. At each stage, if the success was not complete, there was at least a decided improvement.

In 1885 or thereabouts some trials made on board the despatch boat, *Voltigeur*, were so satisfactory as to warrant a report being made in favor of the Belleville boilers, which were soon afterward brought to public notice by trials made on a larger scale on board some liners of the Messageries Maritimes.

The navies of France, Great Britain and some other countries then equipped a relatively large number of their large ships with these boilers, which were still further improved by the substitution of cast and pressed steel for cast iron and by the adoption of the Serve tubes in the lower rows.

An important modification consisted in dividing the boilers into two parts: the steam generator, so-called, and the feed-water heater or economizer, separated from each other by a combustion chamber receiving injections of air and preventing the burning of the gases in the chimney.

This arrangement has given some very good results on land, and seems to have been as successful on board ships.

At any rate the Belleville boilers, such as they are to-day, have proven in numerous applications, and especially in the British Navy, where they were submitted to some very severe tests, that they were particularly well adapted to the requirements of warships. Some of the newest and heaviest warships of the French Navy, now building in the yards, will be equipped with Belleville boilers.

Lagrafel and Allest Boilers.—Next to the Belleville boilers, the water-tube boilers used for the longest time on large ships in the French Navy are those of Lagrafel and Allest.*

After passing several official tests and trials showing their good qualities and capacity, they were placed on board of not less than twenty men-of-war, from the *Bombe,* where they took the place of

* These boilers, patented in 1888, were an evolution of the Barret and Lagrafel boiler dating from 1870.

locomotive boilers, to the *Guichen* of 2 500 h. p. They were in almost every case the subject of favorable reports attesting their endurance and their easy maintenance.

This type attained almost at once this high degree of efficiency, and the only improvements worth mentioning were the steam cleaning of flues, the fastening and expansion of tubes to headers, and the use of special tubes in the lower rows.

Unfortunately certain breakdowns and a grave accident on board the *Jauréguiberry* induced the Navy Department to abandon, perhaps a little hurriedly, this type of boiler. Nevertheless, they have been satisfactorily used in several foreign warships, in the fleet of the Fraissinet Company and on the two well-known packets of the Calais-Dover line, the *Nord* and *Pas-de-Calais.*

Niclausse Boilers.—These boilers, which have taken such a prominent place in the principal navies of the world, were not used on large ships until 1894. They were put on board the *Friant* at that time and gave such good results for the following three years that they were rapidly installed on several ships, and some of the most recent French battleships have been equipped with these boilers.

Some important improvements have been made. The tubes which were originally made in two pieces are now made in one; the uptakes or collectors are made of pressed steel instead of malleable iron; other changes have improved the circulation and facilitated the taking apart. Thirty-two French warships are now equipped with Niclausse boilers and among them is the *Conde* of 21 000 h. p., which has just passed successfully through a trial test lasting four days.

Small Tube Boilers.—In 1896, after being successfully used on board torpedo-boats, the small tube boilers of the Temple type were tried on board some battleships, particularly on board the *Château-Renault,* the *Montcalm* and the *Jeanne d'Arc.* Although results show that there is yet room for improvement, it is safe to predict that in the future this type of boiler will be extensively used on the different classes of warships.

In all the trials and practical applications of water-tube boilers in warships, it has been found that they are peculiarly well adapted to naval tactics, and that their rather low water capacity, which at

first gave rise to fears as to safety, is now considered a fundamental desideratum of the elasticity and perfection of running and working so necessary in the evolutions of a warship.

The mixed system advocating partly the use of ordinary tubular boilers and partly the use of water-tube boilers has not found any supporters in France.

The success of water-tube boilers has been the reason for the construction everywhere, but particularly in France, of boilers evolved from or improved upon the prototypes already in use. Such are the Montupet, the Turgan and Foy, the de Dion and Bouton, the Duchesne, the Solignac and Grille boilers, etc., which have already been used on land, but have not yet been tried enough at sea to warrant their adoption as marine boilers.

Water-Tube Boilers on Board Merchant Vessels.—In the merchant service, the return flue tubular boiler is still used on account of its peculiar qualities; water-tube boilers, however, are beginning to be introduced. In France, besides several minor instances, some large liners of the Messageries Maritimes have been equipped with Belleville boilers; the vessels of the company carrying the mail between France and Corsica have been equipped with Niclausse boilers. The Compagnie Générale Transatlantique, anxious to ascertain the advantages and the drawbacks of water-tube boilers, has equipped two of its vessels, one with Belleville boilers and the other with Niclausse boilers.

Trials made also on a large scale in foreign countries will doubtless further the adoption of water-tube boilers for the merchant service, and, especially, for the great liners. The results of experience as well as the first cost and maintenance will decide the choice between the different types.

Piping.

The elevation of pressure has caused great difficulties in the piping. After several accidents, it was decided to abandon, in all main steam collectors, the system of elbow expansion for high steam temperatures. This system is only used with safety now for small diameters (under 100 mm.). Above this, the tubes are divided into straight sections, and the expansion is taken care of by means of sliding or slip joints.

The fault of these joints is that the internal pressure tends to push the tubes apart and is thrown back against the supports which must necessarily be strengthened. This difficulty is overcome when it is possible to cross at right angles the consecutive sections; one of the tubes is then closed at its extremity and pierced laterally with orifices through which the steam passes. Around this intake passes the other tube which is traversed by the first tube through two packing glands. The two tubes are then free to slide independently of each other, and the pressure is not transmitted to the supports. The use of this sliding joint has become quite general in the last few years.

Moreover, there is a tendency to replace all copper pipes by steel pipes. In the French Navy, this is the rule for all diameters greater than 100 mm. This gives greater strength and resistance, especially at the connections of the flanges which are always so many weak joints in copper pipes.

The danger of oxidization seems to have been overcome with some precautions and with the use of special steels. At any rate since the substitution of steel for copper in pipes, the repairs and accidents, so frequent heretofore, have become very rare.

Miscellaneous Apparatus.

Since the introduction of high pressures, the boilers can only work with perfectly fresh water, and, therefore, distilling machinery has become quite an important factor. The aim has been to increase the output and to facilitate cleaning. This has been obtained by guiding the circulation of salt water by means of screens and in grouping the heating areas in series easily taken apart.

The best models are those manufactured by Mouraille, by the Société de Constructions Navales (formerly Établissements Satre) and by MM. de la Brosse and Fouché.

These apparatus are often coupled in tandem in order to run singly or in pairs. The triple action has been abandoned as being too complicated.

The heating of the feed-water, which is used more and more on merchant vessels, has not yet been generally adopted on large warships; on the other hand, it has been successfully used on torpedo-boats by means of a special design due to M. Normand.

To avoid the passage of oil and greasy matters into the boilers where they are so detrimental, especially when subject to high pressures, a system of filters or purifiers has been installed either in the tank as with Normand's filter, or in the feed current as in the models made in the shops of Penhoët and in those of the Société de Constructions Navales.

Lastly, French constructors, and particularly MM. de la Brosse and Fouché, have endeavored to improve the steam superheaters, thus increasing the capacity and efficiency of the boilers.

Propellers.

The growing adoption of twin-screws in warships and merchant vessels and of triple-screws in men-of-war has already been mentioned.

In regard to the design and proportions of the various parts of propellers, no special studies have been made in France during the last fifteen years. Nevertheless, the outline of screws has been more or less modified by data obtained by experiments and sometimes by theoretical considerations. It has been recognized that the rules to be followed should take into consideration the differences in the types of vessels and in their motors and to find whether the propeller best adapted to a certain type in a smooth sea was as good in rough weather.

The best average pitch and its most advantageous repartition in practice has been established by experiments.

To lessen the resistance to rotation, the cutting or entering edges were thinned out; the thickness of the metal being increased rather at the other end, and otherwise around the hub, it was distributed between the suction face and the propulsive face. The use of highly resistant bronze on fast vessels and the substitution of bronze for cast iron on several merchant vessels of moderate speed have also been improvements in the construction of propellers.

The shape of a saber blade has been used often in order to lessen the vibrations. Blades inclined toward the rear have also been adopted, and experiments have been made with variable pitch lengthwise; but nothing certain has yet been discovered in that respect, for sometimes it was found convenient to increase the pitch and

sometimes it was found best to decrease it in the direction of the axis to the tips of the blades.

Some engineers have adhered to the design of screws which makes the pitch somewhat smaller at the entrance than at the exit, even if it were only not to have the reverse in the casting. It was also sought to obtain a very regular back surface, presenting an almost constant pitch toward the entrance. Some such screws put on the ships of the Compagnie Générale Transatlantique and with a blade angle of 9° to 15°, inclined toward the rear, have given very good results.

For torpedo-boats and destroyers, M. Normand, guided by a long and enlightened practice, has designed some propellers which have given remarkable results, as, for instance, those on the *Forban, l'Arbalète,* etc.

Among the tools let us mention a special machine installed in the shops of the Loire by M. Boulogne. It consists of an emery wheel, the axis of which, mounted on universal joints, can move freely in all directions above the propeller; this arrangement permits the correction and machining the faces of the blades so that the same mathematical exactness can be expected as is required on the plans.

With these improvements made in experiments or in the technical construction of propellers, the question of screws has been, in France, the subject of interesting theoretical investigations; a few of them will be mentioned in chronological order:

In 1889, M. Doyére studied the function called by him the "effective surface" of the propeller, the consideration of which enabled him to establish an empirical formula giving, with a certain precision, the value, $\frac{F}{N^3}$. He also treated the question of multiple screws actuated by the same shaft.

In 1892, M. Drzewiecki showed the influence of the angle of attack upon the efficiency, and recommended the adoption of propellers with constant angles of attack.

In 1893, M. Normand called attention, for the first time, to the rupture of water cylinders in motion, the phenomenon known and studied later under the name of "cavitation"; afterward he demonstrated the necessity of obtaining a large propulsive area and gave

a formula as a guide in the determination of the necessary minimum.

In 1895, a paper read before the Association Technique Maritime showed analytically the geometrical result of the rotation of the blade of a propeller around its hub and brought forward the advantages that could be derived therefrom.

In 1896, M. Piaud presented to the same Society a paper on propellers set in recesses applied to light-draft vessels.

In 1900, M. Rateau, in a masterful study, gave a general theory which threw more light on certain phenomena hitherto uncertain, such as the influence of the back of the screw, of the thickness and section of the blades, etc.

Since, some interesting papers by MM. Delaporte, Brosser and Alheilig have added their quota to these valuable researches.

Propellers of Autoboats.—Without infringing upon the question of internal combustion engines and reverting to the experimental side of the question of propellers, which side must perforce be the most important, in closing this paper, mention must be made of the propellers of autoboats, the evolution of which has been so sudden and so important.

These small boats, equipped with explosion motors, have propellers which can be replaced so easily and at such little cost that we may hope to gather from these experiments, in a near future, some important data that will certainly help to improve the design and construction of propellers in general.

TRANSACTIONS

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

DISCUSSION ON

MARINE ENGINEERING.

By Mr. W. Carlile Wallace, Sir William H. White and Mr. Leslie S. Robertson.

W. Carlile Wallace, Assoc. M. Inst. C. E., New York City.—Those who go down to the sea in ships all know that the human stoker is a most unreliable machine, and he is one of the greatest difficulties with which the engineer staff has to deal. For this reason the introduction of a satisfactory mechanical stoker at sea would be one of the greatest possible boons, both to those immediately connected with the working of the vessel, and also to the owners. So far, the application of mechanical stoking to marine work has been almost exclusively restricted to vessels on the Great Lakes. Mr. Wallace.

In 1903, the speaker had the pleasure of taking a three-days' trip in a vessel fitted with chain-grate stokers applied to Babcock boilers. From a mechanical point of view, the working of these stokers seemed to be fairly satisfactory, and the absence of smoke was a most marked feature of the installation. On the other hand, observation led the speaker to believe that this latter advantage was obtained by the admission of an excess of air to the fire which militated very much against the economical working of the boiler.

On the Lake steamers, ordinary coal is used, the large lumps being broken into small pieces. The grates are of the endless chain type, and the fuel is fed into a hopper above the chain.

Personally, the speaker has had considerable experience with the use of the sprinkling stoker, as applied to the Scotch type of boiler,

Mr. Wallace. and believes that the application of this type of stoker would be attended with much more economy, and that except, possibly, in most exceptional weather, the motion of the vessel would not affect the sprinkling action; in fact, the makers of one type of sprinkler stoker have fitted it in a steam yacht, and positively assert that it gave no trouble on this score.

One of the greatest difficulties hitherto in the use of mechanical stokers is the excessive amount of repairs. When this is overcome, there is no question that there is an immense field for the use of the mechanical stoker at sea.

The speaker is pleased to note that Professor Durand speaks so favorably of the Ellis and Eaves induced draft system. For eight years, he has had principal charge of that department for Messrs. John Brown & Co., Sheffield, England, and recently the point has been reached where the cost of installing this system is very little more than the Howden draft. One of the principal difficulties in induced draft is that, owing to the high temperature of the gases to be dealt with by the fans, the latter must be of large diameter, if they are to be driven direct by an engine. This objection only applies to small installations where the volume of gases to be dealt with is small, but in large installations, when a number of boilers can be so connected that one fan has to handle a large grate surface, the diameter of the fan necessary to deal with the volume is always sufficient to give the required water gauge with an engine speed not exceeding 300 rev. per min.

With regard to Professor Durand's remarks on oil burning, the speaker confirms all that is said under the head of "Advantages," as they agree very closely with his own experience which was gained while conducting a most exhaustive series of tests to ascertain the most advantageous method of applying the Ellis and Eaves system of induced draft to the burning of oil. These tests all showed a most distinct gain in economy with oil fuel by using an air supply heated to about 300° fahr. It also allowed a much larger quantity of oil to be burned without the production of smoke in a given cubic capacity of furnace, which is a most important factor when forcing a boiler. With oil having a heat value of 18 490, the evaporation was 16.1 lb. of water per pound of oil from and at 212° fahr., being an evaporative efficiency of 84 per cent. With a Scotch boiler, having two furnaces, 3 ft. 9 in. in diameter, it was possible to evaporate 9 500 lb. of water per furnace from and at 212° fahr., or an equivalent of about 600 i. h. p. on a marine engine, this absolutely without a sign of smoke. This is fully 30% more than would have been possible with coal of the best quality.

All attempts to burn the same quantity of oil with cold air resulted in the production of the blackest possible smoke. Oil soot

Mr. Wallace.

is highly inflammable, containing more than double the volatile matter in ordinary coal soot, and, if allowed to collect to any extent in the uptakes, disastrous fires may result. To prove that fires of this kind were due to the formation of smoke and subsequent deposit of soot, the boiler in question was run for five days, night and day, without ever showing a sign of smoke at the chimney, with the result that, at the end of that time, the surfaces of uptake and chimney were just as free from soot as when the trial started. The back of the combustion chambers was not protected by brick lining, but a block or pedestal of firebrick was placed in the center of the furnace against which the flames of the oil burners were projected, thus breaking up the flame and throwing out the heat against the sides of the furnace.

No hanging bridges were used, they were not found necessary. Naturally, it was not possible to maintain a mean evaporation of 16 lb. of water per pound of oil during the whole five days, so the speaker quite agrees with Professor Durand in his estimate that 14 lb. of water per pound of good oil may be taken as a fair average. On the other hand, the consumption of steam used in atomizing tends to reduce the value of the above estimate, and if compressed air is used, the power to produce same may be taken at fully 5% of the value of the steam produced.

Although the actual evaporative efficiency of oil may be taken as from 25 to 33⅓% better than coal, the savings which are effected in bunkering, less storage capacity, no trimming and less stoker, have led the speaker to the conclusion that with oil at from 75 to 100% more per ton than coal, an owner could run his ship as cheaply with the one as with the other.

There is just one other point which the speaker would like to treat on, and that is the apparently low efficiency of the water-tube boilers which have been fitted in vessels of the mercantile marine. Most careful tests have shown the efficiency of the Babcock and Wilcox boiler to be quite equal to the Scotch marine boiler; on the other hand, in service at sea, it has been found that the rate of coal per horse power is in some cases as much as 20% in favor of the Scotch boiler. The superintending engineer of one of the largest users of the marine Babcock and Wilcox boiler accounts for this from the fact that his great difficulty was to get the stokers to work the fire satisfactorily; that, owing to the very large capacity of the furnaces, the tendency of the stokers was to fill the furnaces up until they almost choked, and then sit down and do nothing, with the result, of course, that the economy was anything but what it ought to be; and that they found, comparing their ships which had Scotch boilers with those with Babcock boilers, that they were using about 2 lb. of coal per i. h. p. in the latter against 1.5 or 1.6 lb. in the

Mr. Wallace. former. This company uses a very poor class of coal. Until some satisfactory form of stoker is applied to the Babcock boiler, it will not be satisfactory at sea.

Professor Durand has referred to the *Inchdune*. In regard to superheating in marine practice, this boat is still continuing to give good results. She has averaged practically 1 lb. of coal per i. h. p., taken over 1 year. With regard to the superheater itself, it is constructed of tubes about $\frac{1}{8}$ in. thick and 1 in. in diameter, and some time ago, one of these tubes was cut out to see if any corrosion could be found. The tube was cut right down the center, and in no part was any sign of wasting found in the tube. The speaker thinks that superheating is the direction in which engineers should go in marine work, as it seems to be one of the few places left where economy can be had. The tests, so far as could be ascertained, taken over an extended time, showed a saving of about 10% when the superheater was in action, as against when it was shut off.

Sir W. H. White. SIR WILLIAM H. WHITE, PRESIDENT, INST. C. E., London, England.—The subjects with which Professor Durand has dealt are all important. As to the use of mechanical stokers in ships, it must be noted that on the Great Lakes only limited tests can be made, and the full trials required must be made in sea-going ships, subjected to heavy rolling and pitching, which develop forces that interfere with the action of gravitational apparatus. Moreover, it is a good principle in ship equipment to work with the minimum of mechanical appliances consistent with economy. Constant demands are being made to put into ships more and more mechanism, which means more maintenance, but this must be resisted as much as possible.

The difficulty with stokers is undoubtedly great, and the work is hard. If mechanical stokers could do the work, and the often erratic human stoker could be dispensed with, it would be advantageous. This result has not been reached afloat and, perhaps, not even on land. A gentleman of large experience as a mechanical engineer on a great railroad stated recently that, after experiments on a large scale, he had become convinced that with properly trained and disciplined stokers the advantage lies on the side of the hand-stoking, and he had removed the mechanical stokers in use on that road.

The matter of the "human element" in questions of economy of steam machinery is one that needs to be dealt with. The march of mechanical improvement may be limited, unless care is taken of what can be got out of men, apart from training and proper discipline. In the British Navy, a young fellow is entered as a second-class stoker. He knows little or nothing, but he is put under discipline and turned into a trained stoker. In the mercantile service, the stokers are frequently men of the roughest and most undisciplined nature, and the work is carelessly done with consequent

waste of fuel. Engineers are struggling for decimal points in the consumption of fuel per horse-power hour by means of improvements and machinery and boilers; and yet they largely neglect the economy possible by employing disciplined and trained stokers. Greater care is taken by the great German lines of steamships, where the stokers are well trained and under discipline, and a good judge has estimated the resulting economy at 10%, as compared with ordinary stokers. Sir W. H. White.

In order to secure the best results it is necessary that there shall be trained men in the boiler room as well as in the engine room. We would never have been using high pressure in our engine rooms, if we had been content with the old class of engineers. We cannot afford to have a modern gun put in the hands of an old-style gunner. We used to make boilers in the most haphazard way. Now it is quite understood that boilers must be drawn down and manufactured as carefully as any part of the propelling apparatus. Yet the work of the stokehold is left largely in the hands of men imperfectly trained and undisciplined. It would be an advantage to the great steamship companies to have schools on stoking.

Passing to oil fuel, for which Professor Durand has stated the case admirably, his estimate of about 25% advantage, taking the horse power developed, is substantially what Colonel Soliani gave at Chicago in 1893, after careful investigation. His estimate was based upon the most thorough investigation in Russia, as well as in the United States. If the boilers are built for either coal or oil, they best meet existing conditions. In a torpedo-boat built in England some years ago, the boiler was made exclusively for oil, but the makers afterwards wished they had not done it. The question of a constant and regular supply of oil fuel is important. A boiler designed for coal burning can be used, with good results, with oil, but the contrary is not true. The compulsory use of coal under some circumstances is really the governing proposition. In connection with the design of the new Cunard steamers, this question of oil fuel has been much debated. Those vessels will have to take on board 5 000 to 6 000 tons of fuel for a single voyage and burn 1 000 tons per day. If oil fuel could be obtained with certainty and at reasonable prices, no doubt it would be used. Gravity would do the work in feeding the fires, and the filling of the bunkers would be done easily, while the saving in weight would be something like 1 500 tons and would add correspondingly to the freight-earning capacity. As matters stand, no one can assure the supply, even within the limits of cost that Mr. Wallace mentioned. Those who have to do with the supply of oil have such demands, and the fuel itself is so sought after in the neighbourhood where it is produced, that there is not a sufficient visible supply of oil for marine purposes. The consumption of coal is so enormous in shipping that it

Sir W. H. White. is not possible to look upon oil as taking its place. The price of anything, of course, depends upon the demand. Some of the greatest English railways have had oil-burning engines, and have had to cease burning oil and go back to coal because of cost, and their requirements are relatively small.

In regard to materials used in marine engineering, it would be interesting if the experience of the German boiler-making industry could be given in relation to nickel steel. It is understood that they have been very successful with nickel steel, and the facts would be valuable if recorded. British experience in the practical use of nickel steel for boilers is exceedingly limited; for shipwork, also, it has been little used as yet. Steel up to about 40 tons per sq. in. and 20 tons elastic limit has been provided for in recent warship specifications, but this need not be nickel steel.

Professor Durand has summarized the situation admirably as regards water-tube boilers, but at the time the paper was written he probably had not seen the latest report of the Admiralty Boiler Committee. The Admiralty position at the present time is this: no monopoly is permitted, two types of boilers, the Yarrow and the Babcock, being used alternately. For some years the Belleville boiler was used almost exclusively in the Royal Navy, but, at an early date, arrangements were made to try both Niclausse and Babcock-Wilcox boilers. Great urgency for the completion of ships interfered with these experiments. Other navies were using Belleville boilers largely and taking similar risks. Consequently, for a time, Belleville boilers came to be used almost exclusively in the Royal Navy. Although their use is not now continued in the new British warships, it is but fair to add that Admiral Domville, Chairman of the Boiler Committee, has written a special letter stating that the recent work of Belleville boilers in our Mediterranean fleet is most satisfactory. Experience and careful management, no doubt, have much to do with this latest opinion. The best results in coal economy on a long voyage that have ever been obtained in any of the English cruisers were obtained in a ship fitted with Belleville boilers, but the engineer in charge was especially informed as to the type and took great care in the stokehold organization. This is a further illustration of what management is worth.

The Boiler Committee recommended further that, for a time, about 20% of the total horse power should be put into the Scotch type of boiler, and the rest into water-tube boilers. The speaker had considered this plan in the first ships in which water-tube boilers were used, but set it aside for various reasons. First, it was not favourable to economy of space and weight; and, second, it seemed improbable that stokers could pass readily from the cylindrical boiler with its thick fires to the water-tube boiler with its thin fires and obtain equally good results. The danger was that the

water-tube boilers would suffer from the fact that cylindrical boilers were most commonly used. The Committee after a very short time withdrew from its position, and its last recommendation is that water-tube boilers be used entirely for warships. Sir W. H White.

In the mercantile marine, until it is proved that water-tube boilers will be as economical as cylindrical boilers, and that the repairs will be no greater, it is practically certain that water-tube boilers will be used only in special cases. Mr. Wallace has said that up to date his opinion has been that the water-tube boiler was about 20 or 25% less economical than the cylindrical boiler in actual work, although in carefully made tests both came out the same. The fact is that you must have trained stokers. In the mercantile marine at present, they have no trained stokers, and the cylindrical boiler holds the field. Economy in coal and cost of maintenance are most important considerations, and until shipowners can be assured on these two heads they are not likely to embark on the use of water-tube boilers for sea-going ships, although the change is bound to come.

In dealing with turbine motors, Professor Durand has surpassed himself in clearness and completeness in his statement of underlying principles. The future of turbines will take care of itself. At present there are building in England a considerable number of ships of various types with turbine motors. The crowning instance of what their future is likely to be is to be found in the new Cunard steamers, which will have about 70 000 h. p. installed in them. As a member of the Committee which recommended turbine motors for those ships, the speaker cannot enter into particulars, as it is the desire of the Cunard Company that the details of conclusions arrived at by the Committee shall be treated as strictly confidential. But this much may be said: If those who speak of the recommendation of the Committee, as involving a great experiment, were familiar with the details of the design, they would know that there would have been a greater experiment if reciprocating engines had been used. With turbines there will be a practical absence of vibration, less expenditure on maintenance and lubrication, large reduction of space in a vertical sense and other advantages. The models in the Transportation Section of the Louisiana Purchase Exposition showed that much smaller screws will be used in the new ships than those in the *Campania*, or the later German ships. Moreover, with higher rates of revolution the shafts are much smaller, while no crank shafts are needed. With reciprocating power, immense crank and propeller shafts would be required, and would be difficult to manufacture.

In many respects there is less experimental work in the design which has been recommended than there would have been in building ships with reciprocating engines approaching 70 000 h. p. The

Sir W. H. White.

Committee recognised that it had recommended a step which, in its magnitude, represented the advance made in reciprocating engines during 40 years, and yet made its recommendation deliberately. The steam turbine is secure in its future use, if the gas engine or gas turbine does not take its place.

Mr. Robertson.

LESLIE S. ROBERTSON, M. INST. C. E., London, England.—In regard to propellers, it may be interesting to show what was done in a recent turbine yacht with which the speaker was connected, and for which Charles Parsons designed the propellers. Although Mr. Parsons knows as much as anybody about screws for turbine boats, even in this boat, in spite of the fact that he had worked on lines similar to his previous practice, yet, in order to get the desired speed, two or three different sets of propellers were used. Three propellers on each of the three shafts were first tried, but the trouble with disturbed water and consequent cavitation was so noticeable that only two propellers were fitted on each of the three shafts, and the designs were altered in regard to pitch, surface, etc. These facts are mentioned merely to show that as worked out in practice there must be propeller trials, if the best results are to be obtained with the boat.

In regard to the economical results obtained by the French in their torpedo boats, the speaker has had an opportunity of seeing a great deal of their best practice, and thinks that one reason for the remarkable results which they have obtained is that a high premium is put upon economic results by the fact that the French Government insists that their boats, at full speed, shall carry sufficient coal for, say, 3 000 miles, based upon their coal consumption at slow speeds, that is to say at from 10 to 14 knots. The total weight of coal at slow speeds thus determines the total weight of coal to be carried at full speed. The French designers have, therefore, given very particular attention to getting good results at slow speeds. M. Normand had certainly a very efficient staff of stokers, but he arrived at his results by a very careful attention to detail in designing his engines. He has systematically and steadily reduced the consumption until it is now down below 1 lb. It is certainly a beautiful work, and the results have only been obtained, step by step, by careful attention to every detail.

The speaker had to build some torpedo boats for the French Government on plans of an English firm which had not, at that time, paid as much attention to the question of consumption as French firms had, and when the boats, built on English plans under French conditions, were put in commission, there was difficulty about the consumption. The firm naturally tried to find out where the difference was, not being accustomed to the French methods, and found, among other things, that the French briquettes were better than the Nixon navigation and other kinds of coal.

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DREDGES: THEIR CONSTRUCTION AND PERFORMANCE.

Congress Paper No. 38.

REVIEW OF GENERAL PRACTICE.

By A. W. Robinson, M. Am. Soc. C. E., M. Inst. C. E., M. Am. Soc. M. E., M. Can. Soc. C. E., Montreal, Canada.

Congress Paper No. 39.

DREDGING OCEAN BARS.

J. C. Sanford, Maj., Corps of Engrs., U. S. A.

Congress Paper No. 40.

REVIEW OF GENERAL PRACTICE.

By Jean Hersent, Ingénieur Civil, Entrepreneur de Travaux Publics, Paris, France.

Congress Paper No. 41.

CRANE AND LADDER DREDGES.

By T. Kobayashi, Engr. in Charge of Dredging, Harbour Works, Osaka, Japan.

Congress Paper No. 42.

HYDRAULIC DREDGING ON THE MISSISSIPPI RIVER.

By F. B. Maltby, M. Am. Soc. C. E., Washington, D. C., U. S. A.

Discussion of the Subject by

A. W. Robinson, Montreal, Canada.
J. L. Le Conte, Oakland, Cal., U. S. A.
George Higgins, Melbourne, Victoria.
W. M. Venable, New York City, U. S. A.
C. W. Sturtevant, Scranton, Miss., U. S. A.
L. M. Haupt, Philadelphia, Pa., U. S. A.
W. M. Hall, Parkersburg, W. Va., U. S. A.
W. B. Gregory, New Orleans, La., U. S. A.
F. B. Maltby, Washington, D. C., U. S. A.
J. C. Sanford, Philadelphia, Pa., U. S. A.

Note.—Figures and Tables in the text are numbered consecutively through the papers and discussion on each subject.

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REVIEW OF GENERAL PRACTICE.

By A. W. Robinson, M. Am. Soc. C. E., M. Inst. C. E., M. Am. Soc. M. E., M. Can. Soc. C. E.

In this paper it is proposed to review the practice of dredging in America and the progress made during the last ten years, and to illustrate the present state of the art by recent examples. Machines for land excavation will also be included as these have found a special development in America. The subject thus resolves itself into two main divisions, mechanism for subaqueous excavation and mechanism for dry excavation.*

Much difference naturally exists between America and Europe. The two have had an almost wholly separate growth arising out of a different set of conditions and carried on by a different set of men with but little interchange. Thus even the nomenclature is different. Europe, as the older country, possessed dredging machines when America had none, and favored by time and denser popula-

*In this paper the term "America" is used to mean the North American Continent, and "European" includes Britain. Canadian practice, although borrowing some early European features, follows similar lines to the United States owing to similar conditions and proximity.

tion, her harbors and sea-works have reached an earlier and more solid development than in America, and the dredging machines employed on them were superior to American both in point of numbers and in general excellence of design and equipment.

The reasons for this are found not only in the fact that European seaports had a long start of American seaports and an earlier development, but also that the methods of administration followed in Europe were different. These methods favored the creation of permanent plants to execute gradually large works, while in America the opening up of a vast, virgin country, both on the seaboard and in the interior, required the rapid execution of a great number of works suited to immediate necessities under the small contract system.

This system has given rise to a class of contractors of all grades, who build and own their plant, and as their contracts are liable to be varied both as to locality and conditions, they do not invest largely in special plant. The small contractor is under compulsion to make money out of his immediate contract. He must employ a plant which is adapted to a variety of work, and which does not represent more capital invested than his contract will warrant. Moved by conditions of expediency his outfit is often cheap and temporary. If he builds special tools, he is face to face with the contingency of having no further use for them at the termination of the job.

On the other hand the large corporation, or Board of Harbor Trustees, under the European method of administration, is able to lay out a comprehensive plan of the works under its charge and provide permanent plant adapted to it, which will be assured of employment through a series of years. Thus has developed the large and complete seaworthy dredge of the ladder and bucket type, which is found so frequently in Europe and so rarely in America.

The American contractor has great resourcefulness. He is moved by two powerful instincts which are absent from the European corporation: First, the money-making necessity; and, second, the necessity to "hustle" and complete his contract to make way for the next one.

Contrasting the cheap, wooden dredges of the American contractor with the large and costly steel-hulled dredges of the Euro-

pean harbor corporations, the inference might be drawn that America is behind in this class of work. That the plant of the American contractor has been cheap and inferior by comparison is admitted, but it certainly has been better adapted to his needs, and has been capable of doing efficient work under his conditions.

Within the past ten years, however, the needs of the contractor have been changing. Contracts are increasing in size and importance, and call for a larger and better class of plant. Works of greater magnitude are carried on, and it is the policy of the Government to award larger contracts and allow more time for preparation. Contractors instead of being "rule-of-thumb" men, building their dredges themselves from their own ideas and those of their boss carpenter, are now either engineers themselves, or employ engineers, and are building a very much better class of plant. Ten years ago there was scarcely a steel-hulled dredge in America, now there are large numbers as will be seen by examples in this paper.

In the United States the great bulk of the works classed as River and Harbor Improvements are carried out by contract, and for which an appropriation known as the "River and Harbor Bill" is made from time to time by Congress. Most of these contracts are small and represent sums voted for extension and maintenance as well as for new works. In order to give an idea of these appropriations, Table 1 gives the total sums voted by Congress from 1890 to 1900 inclusive:

TABLE 1.—Appropriations by Congress for River and Harbor Improvement.

1890...........	$25 368 624.89	1896...........	$20 108 128.94
1891...........	2 955 278.87	1897...........	20 992 739.73
1892...........	22 077 285.63	1898...........	14 861 459.56
1893...........	14 277 139.65	1899...........	24 567 538.94
1894...........	19 918 247.55	1900...........	15 417 105.75
1895...........	11 667 115.00		

Foreign visitors to America must be struck with much that is crude and temporary in various things as compared with European

practice, and this comparison applies also to harbor works and dredging plant. America is now being re-built at a rapid rate. The early temporary structures which were the natural concomitants of a young and growing country are being replaced with larger and more permanent ones. In river and harbor works and in railway construction the change may be said to have just begun. The increased size of ocean vessels is fully up to the limits of channel and harbor accommodations and pressing for more, and on the railways, the past decade has witnessed an expansion in the size of locomotives and cars which has practically doubled their capacity. Attractive as these two subjects are, it is not the writer's intention to refer to them further except to point out the important relation between the expanded requirements of navigation and railway interests, and the development of dredging machinery. This relation has created a new set of conditions. The large works now projected to fulfill these conditions call for a class of appliances entirely different from those suitable to the small contractor. Dredging machinery in America is thus in its transition stage from small conditions to large, and the development which is now taking place will result in making possible the accomplishment of large projects which heretofore were prohibitive on account of cost and time.

The expansion of river and harbor requirements has already resulted in the creation of a number of large and powerful dredges during the last few years. That they have not before existed is due to the fact that they were not required by the contractor for the works then in hand, and not to the inability of American engineers to build large sea-going dredges. The American contractor may be relied on to design and build just such a plant to execute his work, that when it is all finished, it will have netted him the greatest number of dollars. At any rate this is the mark he aims at, although the fallibility of the human mind may cause him to fall short sometimes of ideal results.

The re-building of American railways is being accomplished by the expenditure of fabulous sums. Built at first in a temporary way to open up the country at small cost, and for the lighter loads of some years ago, they were entirely right and proper, and no intelligent engineer familiar with the conditions would compare

the construction of these railways unfavorably with the finished and permanent construction of Great Britain. In this re-building the steam shovel is a valuable tool, and will be described later in this paper.

It has already been observed that the growth of the country under the small contract system is responsible for the development of much temporary contractor's plant. While, however, fully appreciating the value of thoroughness and completeness (in the building of a dredge for example), together with good design and workmanship as factors of efficiency and economy in the end, the writer would urge that with the rapid rate of change and progress which now exists, it is easy to go too far in that direction. In earlier days and in European practice, things moved more slowly, and it was a good investment to build most things to last a long time. Now, however, things become obsolete so quickly that it does not seem good policy to build for forty years what we will have to throw away in ten, or less. It is a pertinent subject for inquiry which applies to all engineering structures how best to balance the theory of permanence during the probable life, or probable period of usefulness of the structure, so as to give the best efficiency.

The four principal types of dredge which will be considered in this paper are as follows:

1.—The ladder or elevator dredge;
2.—The dipper dredge with single dipper mounted on a handle;
3.—The hydraulic or suction type;
4.—The clamshell or grapple.

The Ladder or Elevator Dredge.

But few examples exist in America of the ladder dredge, and although extensively used abroad, it does not appear to have found any extended use on this side of the Atlantic. This is owing to the fact that it is, as a type, not well adapted to American conditions. To be more specific, these conditions require an inexpensive and an all-around machine suitable for contractor's use, capable of adapting itself to a variety of purposes and conditions, light on repairs, and handled by a small crew.

Thus for contract work the grapple dredge for the soft tidal work of the coast, and the dipper dredge for the harder and shal-

lower work of the Lakes, furnish the contractor with simple tools more suited to his needs and with which he could make more money than a large elevator dredge.

Elevator dredges are used on the River St. Lawrence Ship Channel, where this type of machine has gained a foothold from early examples imported from the Clyde, the first of which dates back to 1832. These dredges have done very successful work as the local conditions are well adapted to this type. Furthermore, the work being carried on through a series of years, first by the Harbor Corporation and later by the Government, a large and permanent plant could be employed which would not be subject to the vicissitudes of contract work. The ladder dredge is best adapted to ship-channel work in the open, where there is ample space to set the anchorages, and large volumes of material to be dealt with of a reasonably uniform kind, and where the method of disposal is by scows or barges.

The dredged ship channel of the River St. Lawrence between Montreal and Quebec aggregates 60 miles of dredging out of 160 miles of river. The original depth of water was 11 ft. and the channel now about completed is 450 ft. minimum width and 30 ft. deep at low water. The general type of dredge employed on this work is illustrated by the *Aberdeen* in Fig. 1, Plate XIV. It is fitted with buckets of 1 cu. yd. capacity and has a record of 5 740 cu. yd. per day average for 21 days. There are six dredges similar in size and type to the *Aberdeen* employed on this work continuously. Some of them are fitted with very powerful, steel buckets of smaller capacity for working in shale rock. The buckets are illustrated in Fig. 2, Plate XIV. The total amount of material excavated in this ship channel is about 40 000 000 cu. yd. These dredges are noteworthy in their operation as compared with European practice, in that they are able to make very wide cuts at one time. The ordinary width of the channel is 450 ft., and this is regularly made the full width at one time feeding laterally. In the bends the width is from 600 to 750 ft., and these dredges make this width also continuously. This is accomplished by the use of steel-wire rope for the head line instead of chain, and carrying the rope on floats for a considerable distance ahead of the dredge so as to permit the necessary movement without dragging on the bottom. These ropes

FIG. 1.—ELEVATOR DREDGE "ABERDEEN." RIVER ST. LAWRENCE.

FIG. 2.—STEEL BUCKETS FOR ROCK DREDGING.
RIVER ST. LAWRENCE.

are from 2 000 to 3 000 ft. in length and are of steel wire of 1.5 to 2-in. diameter according to strength of current. The rope is wound upon a drum of large size operated by an independent engine. The lateral feeding of the dredge is done by a separate winch and chains in the ordinary way, although wire rope has been used for this purpose also.

Isolated examples of elevator dredges used for the improvement of navigation exist in the United States, but they are used for special conditions and are not treated in detail here.

It is always difficult to transplant a type and to overcome local prejudice, and certainly the objections of the American contractor to the elevator type that it is expensive in first cost, limited in its capabilities, complicated, subject to heavy wear and cost of repairs, requires a large crew, and plenty of sea room in which to work effectively, are well-founded. Much has been done, however, to reduce these disadvantages, and to reduce the wear by the employment of a better quality of steel, so that this is not as great a disadvantage as formerly. The use of manganese-steel pins and bushings for the links of the chain of buckets is now almost universal, and it is quite possible to construct a powerful chain of buckets which will run a whole season through without interruption or delay. Where there is a sufficiency of work of the right kind for such a dredge to do, its large capacity and continuous operation leaving a clean and level bottom will commend it.

The only other extended application of this type of dredge has been for gold dredging. During the last ten years this industry has made considerable advance, although the difficulties contended with have been great, and the failures numerous. This type of dredge is now firmly established as the only successful one for gold dredging, and has followed the experience of the New Zealand and Australian practice. Other types of dredges have been tried for gold dredging, but they have all resulted in failure. The reason is that the endless chain of buckets is the only type which picks the gold-bearing gravel up cleanly from the bottom with a minimum of agitation, which would cause loss of gold, and which retains its contents until it is raised to the screen. The material is also delivered in the center of the dredge to the screen and gold-saving apparatus in a fairly continuous stream. The dipper dredge, on

the other hand, delivers a quantity of material intermittently, requires a separate barge for the washing apparatus, and agitates the material during the act of digging so that much of the gold is lost, and further loss occurs through the door of the dipper which is not water-tight. The suction type of dredge is also a failure for gold-dredging purposes, as a force of suction which is sufficient to lift the sand and gravel will leave the gold behind. Furthermore, this type cannot deal with boulders.

In Fig. 1, Plate XV, is illustrated a gold dredge operated electrically and which may be taken to represent an American type. Most of the American dredges are held in position by spuds and make a radial cut. The New Zealand dredges, on the other hand, do not employ spuds, but are controlled by rope anchorages entirely.

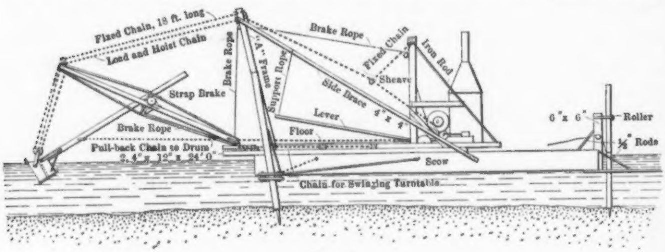


FIG. 1.

THE DIPPER DREDGE.

The development of the dipper type of dredge in America is due to the need of the contractor for a cheap and simple machine which could do a variety of work. In its early, simple form it consisted of a crane or boom on which was mounted a single dipper operated by a hoisting engine. As an example of the simplicity and cheapness of which this type is capable, the small dredge shown in Fig. 1 is illustrated. This dredge has a wooden hull 34 ft. long by 12 ft. wide, made of 2-in. plank nailed together and the capacity is about 175 cu. yd. per 10 hours. The total cost is stated to be about $1 000.*

The adaptability of a dipper dredge to digging a canal through solid ground is illustrated in Fig. 2. Hundreds of miles of canals of small section are built through swampy lands in the Middle and

* *Engineering News*, May 14th, 1903.

Southern States for drainage purposes, in this manner. Such a dredge is well adapted to deal with stumps, roots and other obstructions. A cheap dredge of this kind with a 1.5-yd. dipper will cost say $8 000 to $9 000 complete, and should dig 100 to 150 lin. ft. of canal per day of 20 hours in ordinary material, the canal being

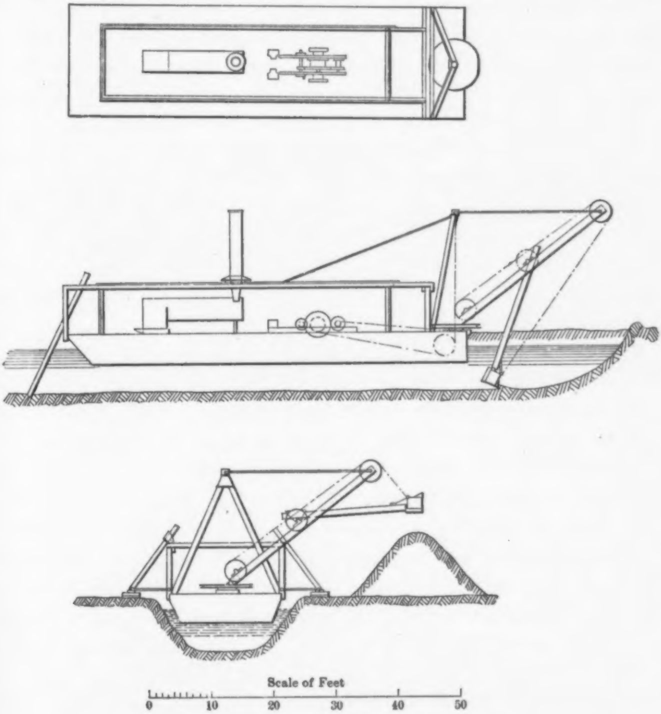


FIG. 2.

8 ft. deep by 20 to 30 ft. wide. These dredges can be built to suit various sizes of canal, say, from 10 to 60 ft. wide at one cut.

The dipper dredge has found its best development on the Great Lakes. The navigational depth of the Lakes is but half that of the seaboard. The length of spud and dipper-handle is therefore kept within easy working limits and a faster speed maintained than would be possible with the 40- to 50-ft. depths necessary on the coast. Added to this is the advantage of non-tidal fresh water of

the Lakes, requiring less adjustment of spuds and less trouble from corrosion and condensing apparatus. The present standard of depth of lake navigation above Niagara Falls is 21 ft. Along the chain of lakes the character of material to be dredged is generally hard, consisting of clay and stones or glacial drift, with some local soft deposits. Consequently the dipper dredge, with its positive application of power to the digging or penetration of the bucket, is better adapted to deal with such material, than the clamshell or grapple dredge, which finds its better application in the soft material and greater depth of dredging on the seacoast.

An example of a good, wooden, dipper dredge of the Upper Lakes is shown in Fig. 2, Plate XV. This is a 4-yd. dredge belonging to the Lake Superior Contracting and Dredging Company. This machine regularly makes a speed of 40 to 45 sec. per dipper load, and has a record of 5 900 cu. yd. in 16 hours. On channel work this dredge has a record of 97 640 cu. yd. per month, while taking off a cut only 2 ft. in thickness, covering 2¼ miles of distance in the month. This was accomplished in October, 1902, and is evidence that this type of dredge can get over the ground at a rapid rate when necessary. In a good bank the best month's record was 111 000 cu. yd.

An example of a dipper dredge for the deeper work of a seaport is shown in Fig. 1, Plate XVI. This is a 7-yd. dredge belonging to the Montreal Harbor Commissioners. The hull, boom and dipper-handle of this dredge are of steel, and the A frame and spuds are of wood. The dipper is hoisted by a single part of steel-wire rope. One of the earliest examples of a large dredge to employ a single rope hoist was Dredge No. 1 of the Montreal Harbor Commissioners, built in 1890 from designs by John Kennedy, M. Am. Soc. C. E.

This dredge was followed by a number of others of the same type improved in detail, and it has been found that while the wire rope does not last as long as chain, it is much more efficient by reason of the great reduction in friction and wear both of chain and sheaves, and in the increase of the angle of lead to the dipper. The life of the rope on these dredges varies from one to four months, those of more recent construction having larger sheaves and drums. A rope will give indications of weakness long enough in advance of its final failure to permit of its being replaced at a convenient

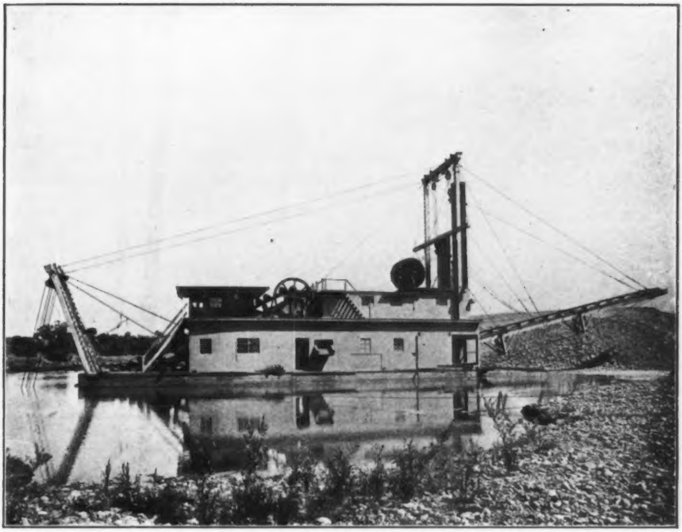


FIG. 1.—GOLD DREDGE. CALIFORNIA.

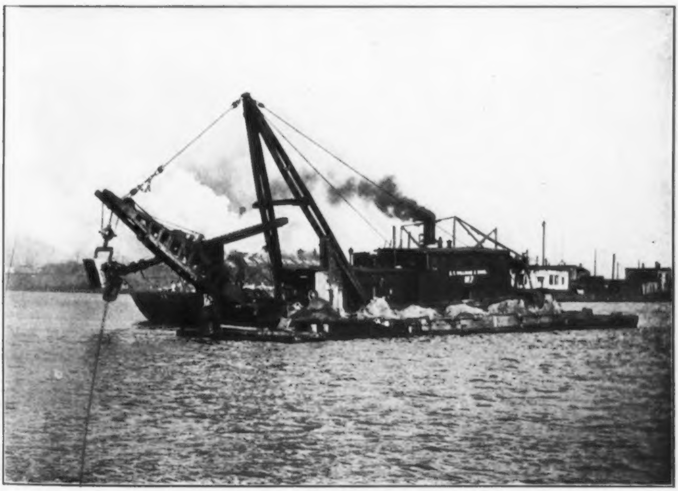


FIG. 2.—FOUR-YARD DIPPER DREDGE. GREAT LAKES.

opportunity. A chain on the other hand, may break without warning and cause delay. A further advantage in the use of wire rope over chain is its increased speed. The efficiency of the dipper dredge as a type depends largely upon its speed, and with direct wire rope a marked increase of speed has been obtained.

The principal dimensions of the dredge illustrated in Fig. 1, Plate XVI, are given in Table 2.

TABLE 2.

Length of hull	90 ft.
Width of "	36 "
Depth of "	10 "
Depth to which dredge can work	40 "
Type of hoisting engines	Double cylinder, non-condensing
Diameter of cylinders	16 in.
Length of stroke	18 "
Capacity of dipper	7 cu. yd.
Diameter of hoisting rope	$2\frac{1}{4}$ in.
Maximum pull on dipper	120 000 lb.
Diameter of main sheaves	8 ft.
Size of forward spuds	42 by 42 in
Material " " (single timbers)	Douglas Fir.
Length " "	60 ft.

The largest dipper dredge yet built is illustrated in Fig. 2, Plate XVI. This is the dredge *Onondaga* owned by Hughes Brothers and Bangs, Contractors, and is at work in the Harbor of New York. The dimensions of this dredge are given in Table 3.

The variety of work that can be done by dipper dredges is surprising to those unfamiliar with them. The machine is in fact a complete floating crane of 50 tons capacity or more. For pulling piles, tearing out old foundations, or preparing for new ones, and lifting heavy weights of all kinds, it is especially adapted. Buried timber or sunken wrecks, which would block a ladder dredge, are by it rooted out and lifted with ease. Where large boulders are encountered, it is necessary to pass a sling chain around the boulder and catch the sling on the teeth of the dipper, and lift. The maneuvering powers of the dipper dredge are such as to render it largely independent of a tug, and handy to work in confined situa-

tions. Standing alone on its spuds it needs no other anchorage and consequently obstructs navigation less than the elevator dredge with its radiating chains and constant motion. By means of its dipper on the bottom, it can maneuver itself in any direction either with all spuds up, or check and swing on one spud, and when the right position is reached, can instantly stop and hold by dropping the remaining spuds. It can push about the scows which it is loading by means of the dipper, reverse them end for end, or swing them entirely around from one side to the other by resting the dipper on the deck of the scow and swinging. It can load the dredged material either into scows, or deposit it on the bank or over a retaining wall. It can dig equally well to the full depth, or cut its own flotation through ground many feet above the water. Having great power concentrated on a single dipper, it is capable of dealing with harder material than the elevator type of dredge, and can handle boulders of large size. The dipper is readily disconnected from the handle by pin-joints, consequently by changing the dipper, the dredge can be quickly converted from a hard-material dredge into a soft-material dredge and *vice versa,* a matter of importance to a contractor. For rock dredging a small and very strong dipper, armed with steel teeth, is used, and for soft material the dipper may be two or three times as large, of lighter construction and without teeth.

TABLE 3.

Length of hull	140 ft.
Width of "	50 "
Depth of "	15 "
Type of engines	Double cylinder, condensing.
Diameter of cylinders	20.5 in.
Length of stroke	24 "
Size of forward spuds (four timbers)	5 ft. square.
Length of spuds	80 ft.
Material of "	Oregon Fir.
Size of dipper arm (single timber)	36 by 36 in.
Length of " "	80 ft.
Material of dipper arm	Oregon Fir.
Capacity of dipper	15 cu. yd.
Depth to which dredge can work	50 ft.

With all these capabilities the dipper dredge is the essence of simplicity, and is under the instant and absolute control of one man, who is captain, engineer, and the soul of the machine. With him is no summoning of the crew, ringing of bells, setting out anchors and losing time in preparation to begin. His crew consists of one cranesman, two or three deck-hands and a fireman, and with steam up he is always ready for work.

As the dipper dredge depends for its effectiveness upon the skill of the operator, the personal equation is most important. Speed and continuity of action are likewise necessary to good results. Therefore, in order that these qualities may be maintained, the mechanism is made very quick in its action, and instantly responsive to the will of the operator without much manual effort on his part. He must be the brain and not the muscle of the machine if top speed is to be kept up. The speed of a good dipper dredge on the lakes may be said to be from 30 to 40 sec. per dipper load, and on the seaboard from 40 to 50 sec. After having dug out all the material within reach, the spuds are raised and the machine is "moved up." This operation is usually performed by dropping the dipper on the bottom as far forward as it will reach, and pulling in on the backing chain. The rear spud remains on the bottom while moving up in order to keep the dredge on line. For this purpose it is made to roll, or oscillate in a fore and aft direction, and when so made is termed a "walking" spud. Should the dredge for any reason get off line, a swinging or lateral movement imparted to the dipper while moving up will correct the error with no delay. The moving-up process should be done in one minute in a well-designed dredge.

The early dipper dredges were of the crane type, and the majority of those in use up to ten years ago did not exceed 2 cu. yd. capacity. In the earlier machines the hoisting engine was connected to the hoisting drum by a positive clutch, but this was later superseded by a friction clutch. This type of dredge has been evolved by experience, and reduced to a system varied of course in detail from which it is not possible to depart to any great extent without detriment, or getting into the region of experiment. The principal stresses are susceptible of calculation from the power exerted by the engines as a basis, and all parts should be propor-

tioned to withstand safely the maximum stress due to encountering immovable resistances under full head of steam.

It has been said that the dipper dredge is indigenous to the Great Lakes. The shallow digging depth and fresh non-tidal waters certainly make it easier to comply with the requirements of design. Nevertheless, many efficient dredges of this type have been built for deep and tidal work. To increase the depth, it is necessary to increase the size of spuds to withstand the bending stress due to greater leverage. As regards slower speed of working at increased depth, the introduction of wire-rope hoist has served to reduce this disability, and it is now possible to build a dredge with rapid, direct hoist which can work to 45 ft. as quickly as the chain-hoist dredges could at 25 ft. A further important point is the angle of lead. This naturally becomes more acute as the depth increases. The wire-rope hoist contributes a great advantage, due to the fact that the line of pull is tangent to the periphery of a very large sheave at end of boom. Thus by properly proportioning the parts an efficient angle of lead and speed of working can be maintained for dredges of this type to depths of, say 50 ft., if necessary.

The difficulties of construction imposed by modern depth requirements of 50 to 55 ft. are fully as onerous on the ladder or elevator dredge as on the dipper. The grapple or clamshell type is not handicapped by depth, and the suction type also can work readily at these depths. These latter are, however, suitable only for soft material, and it is still a problem how best to dredge hard material at great depths. The writer believes that by more careful adaptation to the increased depth requirements, dipper dredges of large power can be built that can better meet these conditions than heretofore, and that the dipper dredge will find a continued development in this direction.

No radical improvement has been made in the dipper dredge during the past ten years. The principal point that might be mentioned is the increasing use of steel-wire rope for hoisting the dipper; a single direct-hoisting rope of large size being used instead of three parts of chain with their accompanying sheaves. The object of this is to reduce the loss by friction of the chain and sheaves, and to increase the speed of working.

Reviewing the advance made in dipper-dredge practice during

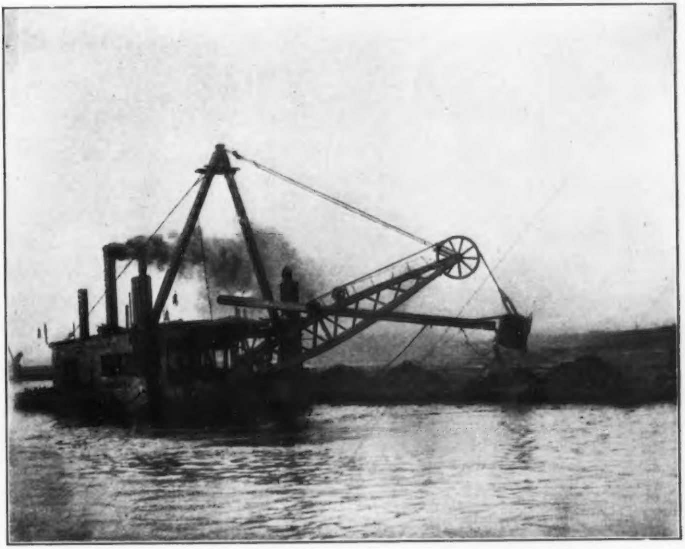


FIG. 1.—DIPPER DREDGE NO. 4. MONTREAL HARBOUR.

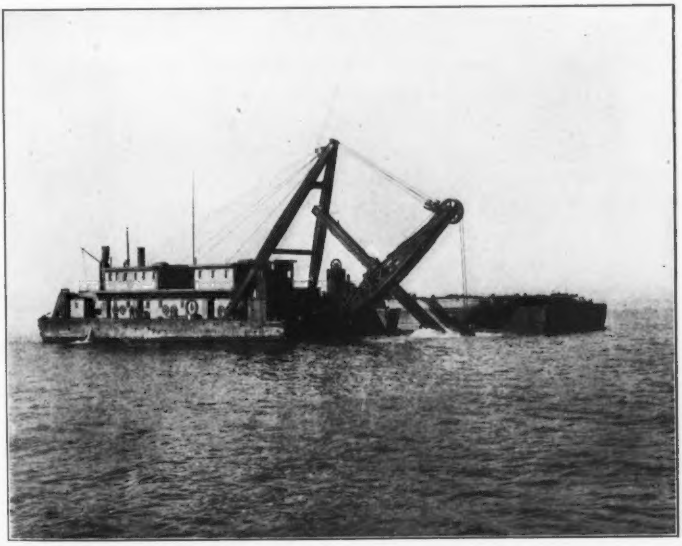


FIG. 2.—TWELVE-YARD DIPPER DREDGE "ONONDAGA." NEW YORK HARBOUR.

the last decade, it may be said that the average size of dipper has increased from 3 to about 6 cu. yd., with occasional examples double these sizes. In these large sizes, designs which answered very well in the small sizes are not now applicable. The use of wire rope has extended and the quality of dredges recently built has been improved. The general practice, however, lacks uniformity and system, and a dredge without some defects, more or less serious, is rare. Much still remains to be done in the direction of simplicity and reliability in service and better engineering.

The Hydraulic or Suction Type of Dredge.

This type of machine has been well known for a number of years and we owe its origin, like the elevator dredge, to Europe. The development in America during the past ten years has resulted in the evolution of one or two special types which are worthy of note.

The hydraulic dredge may be divided into four types:

1.—The sea-going, hopper type without anchorage;

2.—The lateral-feeding, or ship-channel type, with five or six mooring lines attached to anchors;

3.—Forward-feeding, or Mississippi type, with one or two forward mooring lines attached to anchors;

4.—The radial feeding with spud anchorage.

These again may be subdivided into different classes—such as those fitted with plain suction-pipes, water-jet agitators or mechanical agitators. Those of each type may also have hulls, either of rectangular or barge shape, or may be built in the form of sea-going vessels, and may be self-propelling or otherwise. Any of these dredges may also be built to load into barges alongside, as well as to pump through floating pipes or into their own hoppers. A great variety of combinations may thus result.

Much progress has been made during the last ten years in the development of this type of dredge. This development has been more marked in the sea-going, hopper type and in the forward-feeding, or Mississippi type. Ten years ago there were but three or four sea-going, hopper dredges on the Atlantic Coast and these of small size. When those now building are completed there will be seventeen. Among the early ones were the *Gedney* and *Charleston*.

These vessels though small in size and with comparatively simple machinery, proved to be an efficacious means for deepening ocean bars, and it was a natural development to increase the number and capacity of such machines to meet the requirements of the various harbors. These early dredges were followed by the *Cape Fear, Winyah Bay, Comstock,* and several others of similar size and arrangement, all fitted with 15-in. pumps and all built for and operated by the Corps of Engineers, U. S. A. In 1899 the improvement of the entrance to the Harbor of New York on a large scale, was decided on and a single contract for the removal of 40 000 000 yd. was awarded. This gave the opportunity to construct two very large, hydraulic, hopper dredges, and resulted in the *Mills* and *Thomas.** They possess some of the features of the sand-pump dredgers, *Brancker* and *Crow,* which have done such successful work for the Port of Liverpool, but are of somewhat larger size being 52 ft. 6 in. beam and 300 ft. long, while the hoppers have a capacity of 2 800 cu. yd.

The greater number of the small, sand-pump, hydraulic dredges in the United States are built of wood. The argument in favor of wood is, that it is more elastic in case of pounding on a bar than steel, and when sheathed is considered to be more durable than steel in the semi-tropical waters of the South Atlantic. The increasing scarcity of wood is, however, causing it to be abandoned in favor of steel.

At the present time there are ten sea-going, hopper dredges, mostly of small size, either under construction or recently completed for the United States Corps of Engineers.

These dredges will be made the subject of a special paper to be presented at this Congress by Major J. C. Sanford, Corps of Engineers, under whose direction much of the work has been done. They are, therefore, not further referred to here.

The Lateral-Feeding, Ship-Channel Type.—This type is exemplified by one example, the dredge, *J. Israel Tarte,* on the River St. Lawrence.† This dredge was designed by the writer specially to suit the local conditions on the River St. Lawrence, and is capable of making a cut 700 ft. wide and 45 ft. deep at one time. The hull

* See *Engineering News*, February 14th, 1901, for description of these vessels.

† See *Transactions*, Can. Soc. C. E., March, 1904, for an extended description of this dredge.

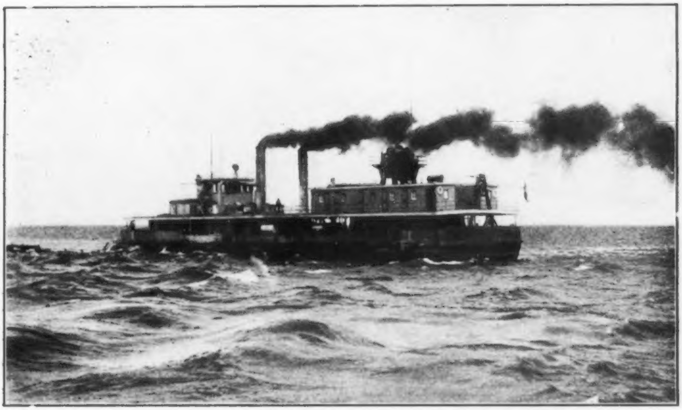


FIG. 1.—HYDRAULIC DREDGE "J. ISRAEL TARTE." RIVER ST. LAWRENCE.

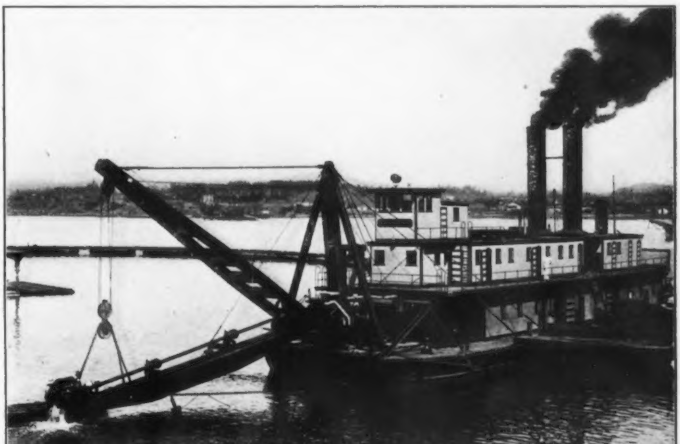


FIG. 2.—TWENTY-INCH HYDRAULIC DREDGE "KING EDWARD." VICTORIA, B. C.

is of steel, 160 ft. by 42 ft. by 12 ft. 6 in. deep, and the main discharge pipe is 36 in. diameter by 2 000 ft. long. The dredge is operated entirely by wire-rope anchorages and the suction-pipe passes through a well in the center of the vessel. The material in which this dredge works is soft, blue clay, and it is excavated by a mechanical cutter. The mooring ropes are arranged in such a way that the operation is practically continuous. The two principal

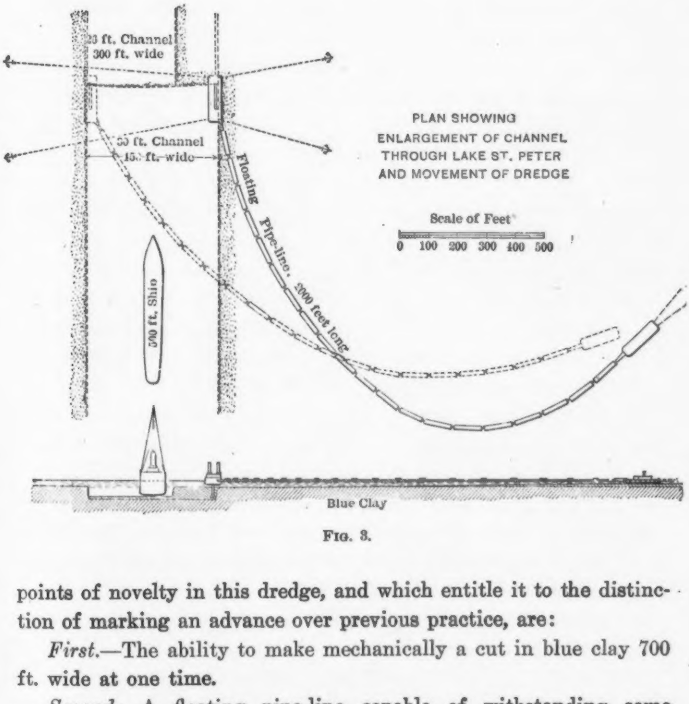


FIG. 3.

points of novelty in this dredge, and which entitle it to the distinction of marking an advance over previous practice, are:

First.—The ability to make mechanically a cut in blue clay 700 ft. wide at one time.

Second.—A floating pipe-line capable of withstanding some stress of weather and wave action. (See Fig. 4.)

These two features cannot fail to widen considerably the sphere of usefulness of this type of dredge where such requirements exist. This dredge also has the distinction of making what is believed to be the largest output of any dredge in the world under similar

conditions, working by the month. This output was 757 100 cu. yd. of blue clay in 26 working days from a depth of 35 ft., delivered 2 000 ft., and was accomplished in the month of September, 1903. This dredge is illustrated in Fig. 1, Plate XVII, and a diagram of its operation in Fig. 3. Its work consists in deepening and widening the existing channel through Lake St. Peter. It has demonstrated its ability to deepen this channel 4 ft. at the rate of a mile and a half per month, at a width of 325 ft.

The Forward-Feeding, or Mississippi Type.—The forward-feed type of hydraulic dredge adapted for shallow work in alluvial rivers is here termed the Mississippi type, because it has received its greatest development on that river; the conditions of navigation on the Mississippi are such that at extreme low water the ever-changing and frequently-forming sand bars make navigation very difficult. In 1892 the subject of dredging as an available means of improvement was taken up by the Mississippi River Commission, but at that time the feasibility of such a method when applied to such a vast river as the Mississippi was greatly doubted. It was decided to construct an experimental dredge and a committee of two, composed of Colonel Charles R. Suter, and the late Colonel Henry Flad were entrusted with the work. It was realized that a much larger capacity of pump than anything that had been previously attempted would be necessary, and the 15-in. machines that were then in use would be valueless. Plans were drawn for a dredge which would have four times the capacity of those then in use, and resulted in the building of the dredge *Alpha.*. Preliminary tests of the *Alpha* were made in 1893, and the first effort to improve navigation in 1894. This dredge, although imperfect in many ways, demonstrated its ability to make a passage through a bar at low water with sufficient effectiveness to afford temporary relief for passage of steamers, and upon the experience thus gained the requirements for the succeeding dredges were formulated. In 1894, the Mississippi River Commission issued these requirements with invitation for competitive designs and proposals to furnish a dredge of large capacity. Out of a number of designs submitted. three were finally selected and ordered built with the avowed object of putting them to the test and ascertaining their respective merits. These three designs were prepared by Lindon W. Bates, The New

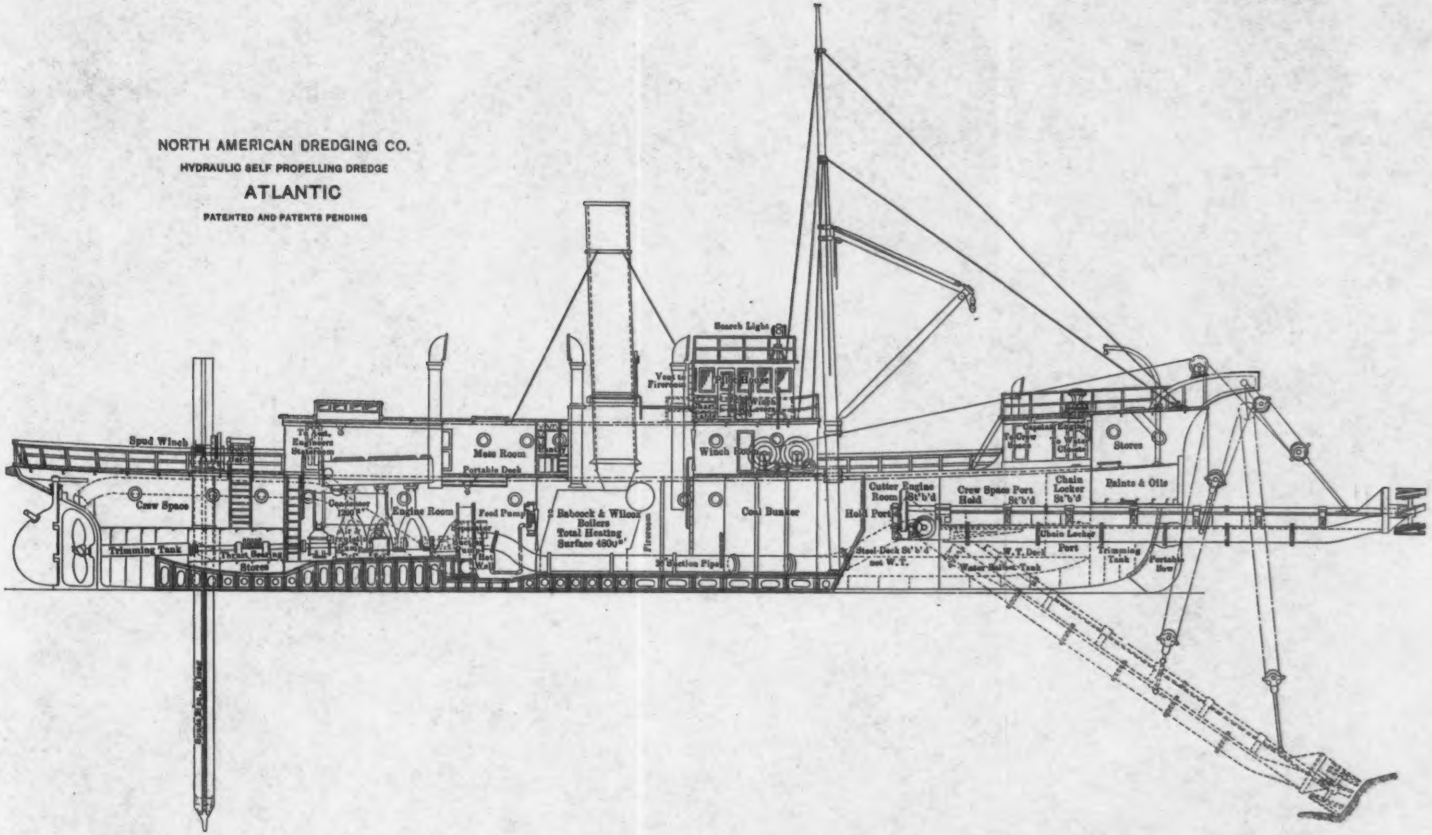
PLATE XVIII. VOL. LIV. PART C.
TRANS. AM. SOC. CIV. ENGRS.
INTER. ENG. CONG., 1904.
ROBINSON ON
DREDGES

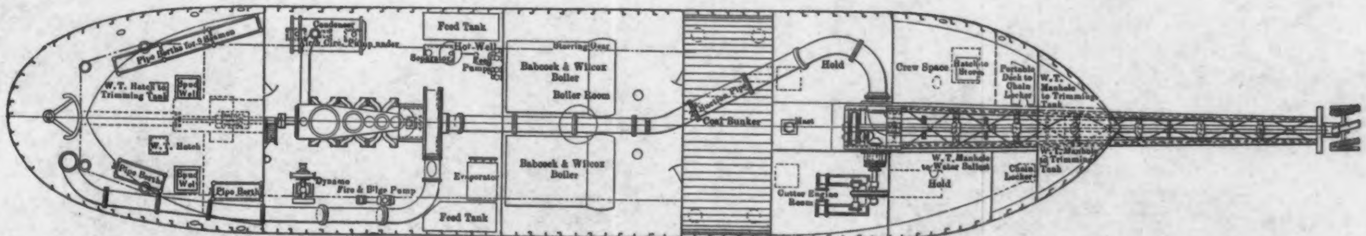
NORTH AMERICAN DREDGING CO.

HYDRAULIC SELF PROPELLING DREDGE

ATLANTIC

PATENTED AND PATENTS PENDING





HOLD PLAN

York Dredging Company and the writer, and resulted in the construction of the *Beta, Delta* and *Gamma*, respectively. The history of these dredges and subsequent ones is exceedingly interesting, and with the results which have been obtained, constitute a record of the most extensive experimental work in dredging which has anywhere been made. Being carried on by the Government, the purely experimental observations were much more extensive and thorough than would be possible under private auspices, and the results have been fully published. A detailed description of the dredges and their performance up to 1898, will be found in a paper by J. A. Ockerson, M. Am. Soc. C. E., on "Dredges and Dredging on the Mississippi."* Many further data are also given in the successive. annual reports of the Chief of Engineers, U. S. A. The subject is also brought up to date with much additional information in a paper by F. B. Maltby, M. Am. Soc. C. E., U. S. Assistant Engineer, which is presented at this Congress. The subject, therefore, is not gone into here in detail.

These dredges have demonstrated that it is entirely practicable to improve the navigation of an alluvial river by dredging, and that after an opening is once formed through the sand bar, it can be maintained with comparatively little dredging, full advantage being taken of the natural erosion of the current.

These dredges being in service only a short time during the low-water season have not had the test as to durability that other dredges would have that are required to work continuously, and on account of this intermittent service and great first cost, they can properly be only built and operated by the Government.

The Radial-Feeding Type.—This type of hydraulic dredge is usually anchored by one or more spuds which serve as an anchorage, the suction-pipe making a radial cut on an arc of a circle about the spud as a center. A number of dredges of this type have been built during the last few years, and their field of operations appears to be increasing. The use of mechanical excavators enables this type of dredge to deal effectively with material other than sand and has consequently greatly widened its sphere of usefulness. Various kinds of rotary cutters have been used with greater or less success, and the United States Patent Office furnishes a remark

* *Transactions*, Am. Soc. C. E., Vol. XL, p. 215.

able array of devices of this kind, but few of which possess positive merit. For the lighter kinds of material almost any form of bladed agitator will answer the purpose, but when the material becomes more difficult as in hard, tenacious, or sticky clay, it is necessary not only to make the cutters very strong but to adapt them to the conditions carefully so as to avoid clogging. In this class of work the pumping apparatus is employed for transportation purposes only, the excavation being done by mechanical means. It is reasonable to suppose that with adequate mechanical means for excavating and disintegrating the material into pieces small enough to pass freely through the pump and feeding it into the mouth of the suction-pipe, that any class of material which can be so treated, can be worked by this type of dredge advantageously. Much improvement has been made in the direction of accomplishing these objects, but much still remains to be done, and at the present stage, the efficiency of the suction-dredge as a type is very sensitive to the class of material which it is working, that is to say, under favorable conditions with good material, which can be handled in large quantities, a large output at low cost per cu. yd. can be reached, but if the same dredge be put into more difficult material, the output may fall off very rapidly so that the work becomes much more costly. Several of the older contracting firms on both the Atlantic and Pacific Coasts now own dredges of this type of large capacity, which are capable of pumping material ashore to distances of from 2 000 to 5 000 ft. They are thus useful in reclaiming land as well as in deepening the channels. In many cases they are used to dispose of material, which may be brought to them in dump scows from another dredge at a distance, and pump this material ashore where it would be of use. A dredge belonging to the Atlantic, Gulf and Pacific Company, working at Oakland, Cal., has successfully delivered material through 6 170 ft. of pipe of 20 in. diameter. Another dredge built by the same company for the Baltimore Water-Works has pumped through a pipe-line 10 797 ft. long.* Part of this pipe-line was, however, down hill to the extent of 10 ft. negative head. The pressure at the pump is stated to have been 28 lb. per sq. in.

In Fig. 2, Plate XVII, is shown a dredge of this type in the Har-

* See *Engineering Record*, March 5th, 1904, for data of this dredge.

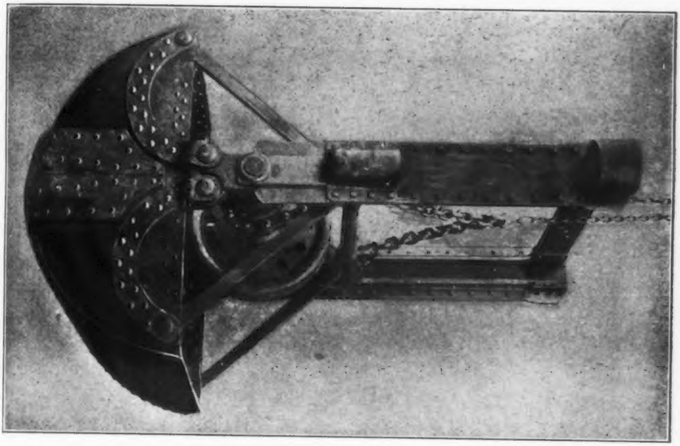


FIG. 1.—TYPE OF CLAM SHELL USED ON ATLANTIC COAST.

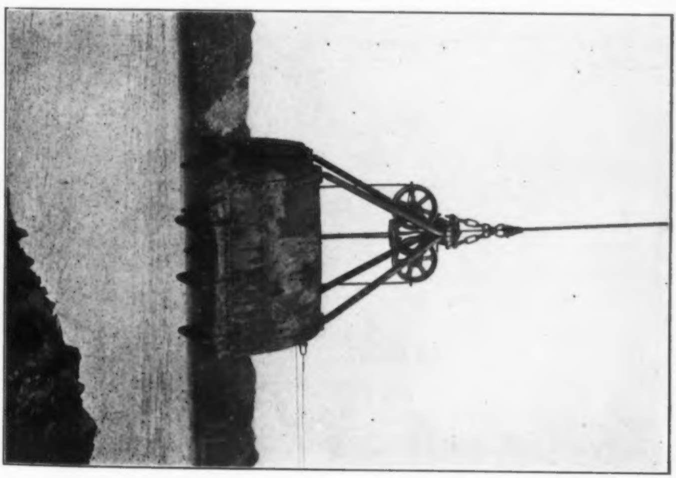


FIG. 2.—CLAM SHELL USED FOR UNLOADING SCOWS.

bor of Victoria, B. C., the material being used for filling in behind a retaining wall and thus adding a piece of land in one of the most valuable portions of the city. This is a self-propelling dredge called the *King Edward*.* It has a composite hull, and is fitted with a 20-in. pump, triple-expansion engines and water-tube boilers.

In Plate XVIII is illustrated the dredge *Atlantic*. This is a radial-feed dredge with spud anchorage and mechanical cutter all in the form of a complete self-propelling vessel with steel hull. This vessel is a good example of the manner in which contractors' plant is expanding to meet modern conditions. This vessel was built for contract work by the North American Dredging Company of San Francisco, Cal., at Camden, N. J., in 1903, and proceeded to Galveston, Tex., where she is now at work. The same company possesses a similar vessel on the Pacific Coast called the *Pacific*.

In the matter of details of the hydraulic type of dredge much improvement has been made in the last few years as the result of experience. Those concerned in the operation of dredging machines will realize the fundamental importance of good details. The value of a dredge lies in its capacity to maintain a high average output, and this can only be done when the general plan is good and when every detail is well-designed and faithfully carried out, so that it can be depended upon not to give trouble. Many dredges may be 80 to 90% good, but the 10 or 20% of poor details robs them of opportunity to do good work. With good design the internal causes of delay in this type of dredge may be confined to replacing parts subject to wear. The wear on the interior of a pump is not now as serious a matter as it was. The greatest wear occurs with sharp sand mixed with stones, and the least with clay or mud. Wear on the interior of a pump may be greatly reduced by designing it so that the flow is nearly uniform in velocity and does not impinge strongly on any one point. Large space in the volute is very desirable. Stones flying from the periphery of the runner will wear the pump much less if they pass into a body of water moving at proper velocity. The pump-runner should always be of steel of the enclosed type. The vanes should not be too close together otherwise small passages and greater friction will result. The passages should be large and have no sharp bends and should be

* See *Transactions*, Can. Soc. C. E., Vol. XVII, 1903 for a detailed description of this dredge.

parallel toward the periphery, not tapering as is usual in a water-pump. This results in slight loss of efficiency but is necessary to prevent solid objects from sticking in the pump. The pump shaft should be strong and stiff and supported independently of the sleeve or stuffing-box in the pump. The passages through the pump should always be slightly larger than the openings into the mouth of the suction-pipe, otherwise obstructions will lodge at the pump.

For most purposes the side-suction pump is to be preferred for the reason that it gives larger passages with easier bends than the double-suction. It also affords the simplest combination with a triple-expansion marine type of engine, which for ordinary conditions is the best motive power at this writing, although there are indications that other motors will find an application in the near future. The chief advantage in the double-suction pump is that it is balanced and consequently does not need a thrust bearing. This advantage is, however, less important than those above stated for the side-suction, and is subject to the further objection of increased internal friction surface and obstruction of the suction-pipe by the shaft. There is no difficulty in applying a marine-thrust bearing to the shaft for the side-suction pump and the end-thrust is trifling if compared to that due to a screw propeller where all the work is converted into end-thrust. Moreover it is possible to design a side-suction pump so that the end-thrust is nil. Double-suction pumps have, however, found much favor on the Mississippi River dredges as described in Mr. Maltby's paper, and have given higher efficiency than the single-suction pump of the *Delta*, which is in fact the only side-suction pump of note on the river. The writer thinks, however, that this difference is due to causes other than the arrangement of the suction as a comparison of the designs will show. There are also local reasons favoring the adoption of the double-suction pump on the Mississippi. These dredges require two suction-pipes in any case and horizontal engines are preferable on account of shallow hull and limited head-room. Furthermore, narrow passages in the pump are not a vital objection on these dredges as the material is sand only. Therefore questions of symmetry of design will justify the adoption, in this case, of the double-suction pump and a horizontal engine on each side.

The floating pipe-line of the hydraulic dredge continues to be

FIG. 1.—STEAM SHOVEL LOADING TRAIN OF CARS WITH HINGED SIDES.

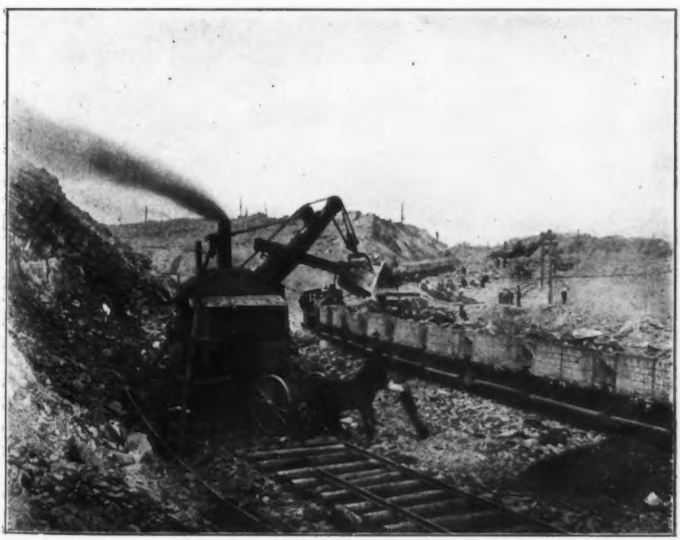
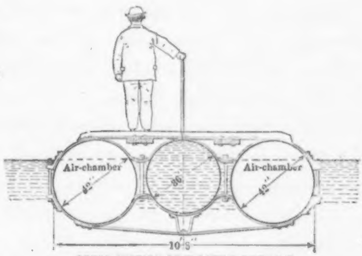


FIG. 2.—SHOVEL LOADING TRAIN OF SMALL CARS.

a subject for experiment. In quiet waters, thin-sheet steel pipes and almost any kind of a float will answer the purpose. The wear on these pipes is slight even in sand, and when thin they deteriorate more from rust than from wear. For heavier work and in exposed situations the sections should be in long lengths and solidly built. A successful example of heavy pipe-line for work in waves is found in the dredge *J. Israel Tarte,* already referred to in this paper.



CROSS SECTION OF FLOATING PIPE LINE

Fig. 4.

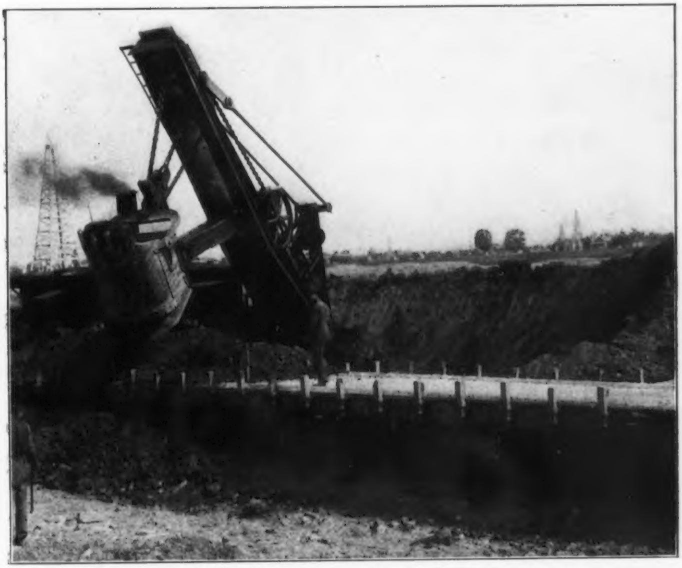
The question of power and efficiency of the hydraulic dredge is one which varies between wide limits. An efficiency in the pump of 60 to 65% is all that can be fairly expected, although some pumps on the Mississippi showed 74%, but were deficient in other respects. The power required depends on the total head and the velocity in the pipe. For economy in power, it is advisable to employ as low a velocity as will transport the material. For economy of dredging, however, large output is necessary, and hence a high velocity which is wasteful in power but productive of more work is frequently adopted. A velocity of 7 ft. per sec. in clay or mud, and 10 ft. in sand will give good results, but 12 to 16 ft. are sometimes employed for moderate distances and large output regardless of economy.

The question is often asked, what percentage of solid matter can be carried? This cannot be answered definitely. It may vary from 0 to 75%, or even more. Favorable material at short distances can be pumped with only enough water to lubricate it on its passage. On the other hand should the material become difficult, the percentage may fall off to a small figure. In general it may be said that it is less difficult to transport a large percentage through a pipe-line than it is to introduce it there uniformly and without choking. Therefore the appliances for mooring and feeding the dredge uniformly, and for digging, cutting, or agitating the material, and introducing it into the suction-pipe, are of the first

importance. If the material be sand or mud but little agitation is necessary and sand alone can be pumped up in large quantities without any agitation, but depending on the force of the suction. On the Mississippi dredges, mechanical agitators have been discarded entirely in favor of water-jets. This because in free sand the water-jets answer every purpose, and because of the difficulty in keeping mechanical cutters free from break-downs or repairs. The latter difficulty is, however, one of design and is reasonably avoidable.

Reviewing the hydraulic type of dredge, great progress has been made during the past decade and the sphere of usefulness of the machine as a type widened. The recognized effective size of dredge for pumping ashore has increased from 15-in. pipe to 30-in. Shore-pipes of 30-in. diameter are now used in several examples, and at least one example of 36-in. is in use. Entirely floating pipes of 36 in. are used, and the writer is about to build one of 42 in. Sand pumps in hopper dredges are not subject to the limitation of handling the pipes and hence can be made any size that is desirable. Mechanical cutters have been improved so that they can deal with fairly firm material, and the mere increase in size of pumps and pipes has served to reduce the difficulty of choking with obstructions, etc. British and Dutch practice appears to be still limited to sand-pumping, and for firm material, resort is had to the elevator bucket type. Pumps have been made more durable and capable of delivering to greater distances. The floating pipe-line can now be built in more seaworthy manner, so that it can be used in rougher water than heretofore.

Further improvements are needed in greater perfection of detail, a wider range of mechanical-cutting apparatus, a better method of flexible pipe-joint than the rubber sleeve or ball-and-socket, and a motor for the pump which will run faster than the triple-expansion engine and permit of smaller and better pumps to be used. Such a motor will be developed from the steam turbine, although the present state of the art does not admit of the combination, as turbines are not yet built of moderate power and slow speed adapted for direct connection to dredging pumps. Electric motors will seldom apply, but the possibilities of the oil engine as doing away with boiler and accessories should not be overlooked.



SHOVEL LOADING TRAIN OF STANDARD FLAT CARS.

Up to the present time sand-pumping has been looked upon as the special and favorable field for the hydraulic dredge. Sand, however, on account of its tendency to precipitate can only be carried in limited quantities and causes great wear and abrasion. The writer believes that greater possibilities lie in working clay soils by this method. A much higher percentage of solid matter can be pumped long distances in clay than in sand and with less wear. Some clays become fluid enough to be pumped with 10% of water, or just enough to lubricate them, and are of a soft and unctuous nature so that they will slide very freely in a discharge-pipe. The carrying capacity of a 36-in. pipe with 80% solid matter at 10 ft. per sec. velocity is 7 400 cu. yd. per hour. The writer thinks that this rate is entirely practicable under favorable conditions as far as pumps and pipes are concerned, and that the problem lies in gathering the material at the inlet and disposing of it at the outlet.

The hydraulic dredge is still very wasteful in the matter of power, and in fact all types of dredge are wasteful, the useful effect in proportion to power expended, being greatest in the elevator dredge, and least in the hydraulic dredge. Power is, however, relatively cheap and not the most important factor in the efficiency of a dredge. In a hydraulic dredge most of the power is expended in pumping a large quantity of water through a long pipe at a wastefully high velocity, and accomplishing the transport of a relatively small quantity of material. The simplicity and effectiveness of the operation, however, is such that it is more economical to waste power thus than to adopt other methods involving less power but more complication and cost in other respects. Much may be done to improve matters by making the water carry its maximum load and by cultivating high efficiency in pumps and engines.

The Clamshell or Grapple Type of Dredge.

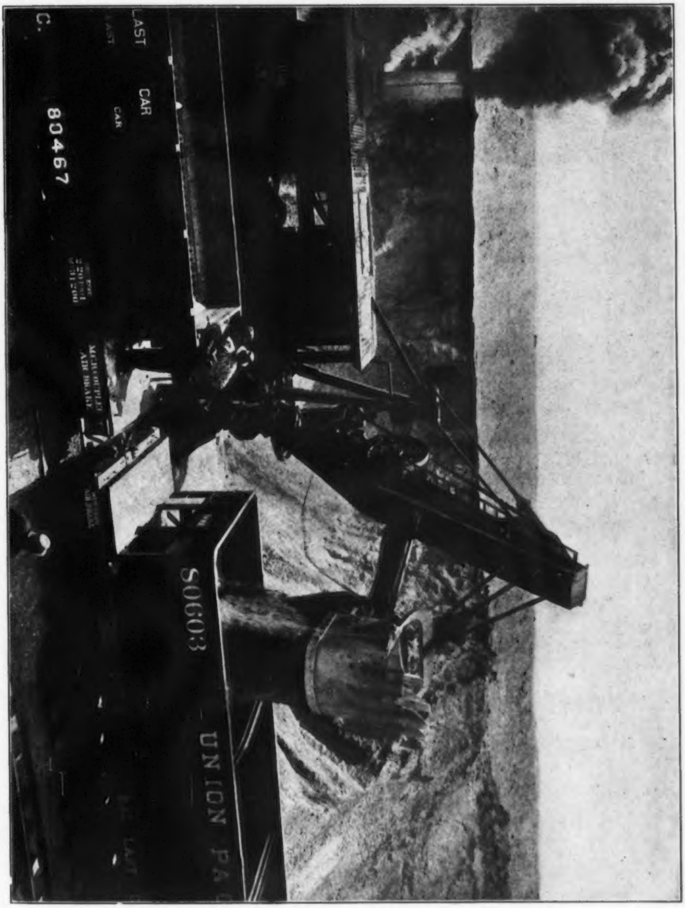
The usual type of clamshell bucket used along the Atlantic Coast is that illustrated in Fig. 1, Plate XIX, which is a bucket manufactured by Theodore Smith and Sons Company of Jersey City, N. J. It is operated by two chains, one for opening and one for closing. The closing chain is attached to the periphery of a wheel or sheave mounted in the frame and arranged in such a way that a powerful

closing action is obtained. These machines are very simple and easily operated and strain their spuds less than the dipper dredge. They are worked by a hoisting engine having two drums side by side operated by friction clutches. The two chains are spaced sufficiently so that by varying the pull upon them the boom is caused to swing as desired, no other swinging apparatus being necessary. This type of dredge is well adapted to soft material and deep water. Several examples exist of dredges with a bucket of 10 cu. yd. capacity, the speed of working being about the same as a dipper dredge.

Many variations of form of bucket are in use, some circular with four leaves, and some with a steam or air cylinder for more positive closing. Special forms are used for picking up stones or blasted rock. A bivalve bucket with simple arrangement of opening and closing ropes is shown in Fig. 2, Plate XIX.

The Steam Shovel.

This type of excavator is introduced here because it forms an important chapter in the history of the development of American excavating machinery. The opening up of a vast interior country required the construction of many thousand miles of railway, and involved various works in which dry excavation was required which afforded a scope for the steam shovel. It is natural that this machine should find its greatest development in America, on account of the stimulus of the cost of manual labor, and the large amount of material to be excavated in a short time in the works undertaken. There is a continual demand for greater power and capacity in almost every line of work, and in this respect the steam shovel is following closely the locomotive and steamship. During the past ten years the hauling capacity of locomotives and the cargo capacity of steamships may be said to have doubled and the same increase is true of the steam shovel. Ten years ago the steam shovel ordinarily in use weighed 30 to 35 tons, and had a dipper of 1.5 cu. yd. capacity. The shovel ordinarily in use to-day weighs 60 to 70 tons and has a dipper of 2.5 to 3 yd. capacity. Larger machines have been built up to 90 tons weight, or possibly more; and a dipper of 4.5 to 5 cu. yd. capacity. The capacity of a shovel,



STEAM SHOVEL LOADING CARS OF 100 000 LB. CAPACITY.

or rather the size of a dipper is, however, limited by the cars for receiving the material and taking it away, and it has not yet been found practicable to build a car strong enough and large enough to receive the discharge from a 5-yd. dipper in rapid succession without considerable loss. A modern shovel for railway purposes has a steel car, 10 ft. wide by about 36 ft. long, mounted on two four-wheel trucks.

It has a dipper usually of 2.5 cu. yd. capacity which it handles at the rate of four times per minute. In Fig. 1, Plate XX, is illustrated a shovel at work loading a train of cars having raised sides. These cars hold about 30 cu. yd. each, and are handled in trains of 20 to 25 cars, so that the total load of a train is 600 to 750 cu. yd. To work these machines to their full capacity, it is necessary to have several such trains hauled by powerful locomotives, and a trackage arrangement so that they can be fed past the shovel as nearly continuously as possible. The railway construction work in the Central and Western States is nearly all done by cars of large capacity hauled by full-sized locomotives. In the Eastern States and for contractor's use, however, smaller dump cars are used, hauled by light locomotives. Such a train of cars is illustrated in Fig. 2, Plate XX. These cars hold from 3 to 5 cu. yd. each, and are hauled by a locomotive weighing 25 tons and having cylinders of 10 in. diameter by 14 in. stroke. They have the advantage of running on a light, temporary track which can be easily shifted as required, but on the other hand, they are inadequate for handling large volumes of material in a wholesale way as are the larger cars and locomotives. In Plate XXI, is shown a large shovel loading a train of ordinary flat cars. Much of the material is spilled as will be seen.

The development of the modern American shovel has evolved a machine of great strength and speed. In the earlier shovels all the motions were performed by one pair of engines, friction clutches being employed. This has now been abandoned in favor of independent engines for each motion so that they can be performed simultaneously and without interruption or delay. The majority of steam shovels now in use employ three parts of chain for hoisting. For the high power and high speeds now required with heavy chains, the same difficulties occur as with the chain hoist in the dipper

dredge. In a large shovel the chain will weigh a ton and a quarter, and travels at a speed of 500 to 1 000 ft. per min., reversing twice per lift, or say, 8 times per minute. Added to this it must run over six sheaves and the number and frequency of bendings is very great. A chain makes two bends passing over each sheave, one bend going on and one bend going off. In a machine having six sheaves and making four dippers per minute, the number of bendings for the entire length of chain will therefore be 96 to 100 per minute. There will probably be 300 links in the chain, so that the number of link bendings will reach the astounding number of about 30 000 per minute. This results in great wear and tear and loss of power. A new shovel, designed to obviate this loss which employs direct wire rope for hoisting somewhat similar to the dipper dredges before referred to, has recently been brought out by the writer. In the dredges, however, three sheaves are employed to guide the rope to the hoisting engines on the dredge. In this shovel, the hoisting drum with its engine is incorporated in the base of the boom so that there is but a single sheave. This steam shovel is illustrated in Plate XXII. The important advantages of this shovel are: direct application of power, less friction and wear, better angle of lead, shorter boom, higher lift, greater speed, and longer and better boiler.

The steam shovel is used for other purposes than construction of railroads. Among these may be mentioned the excavation of iron ore. The vast ore deposits of the Lake Superior region are almost wholly handled by the steam shovel. The iron mines in these regions are either of the open or the underground description. In the open mines, the steam shovel is first used for stripping off the superincumbent material, and then for excavating the iron ore from its natural bed and loading it directly into trains for shipment to the vessels awaiting it on the Lakes. At the underground mines, the shovel is used for loading ore from stock piles on the surface into cars for shipment. All this work is done at a cost so low that it has been an important factor in the development of the steel industry of America by keeping down the cost of production.

Comparing the American type of shovel with the French and German types of excavator with ladder and chain of buckets, the advantage is in favor of the former in point of ability to do rough

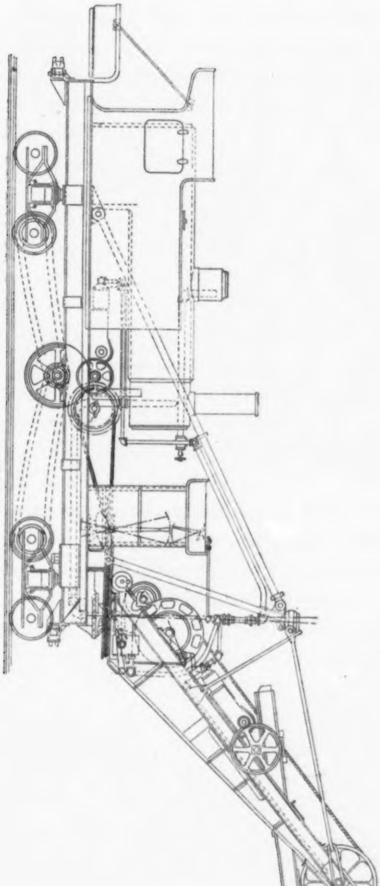
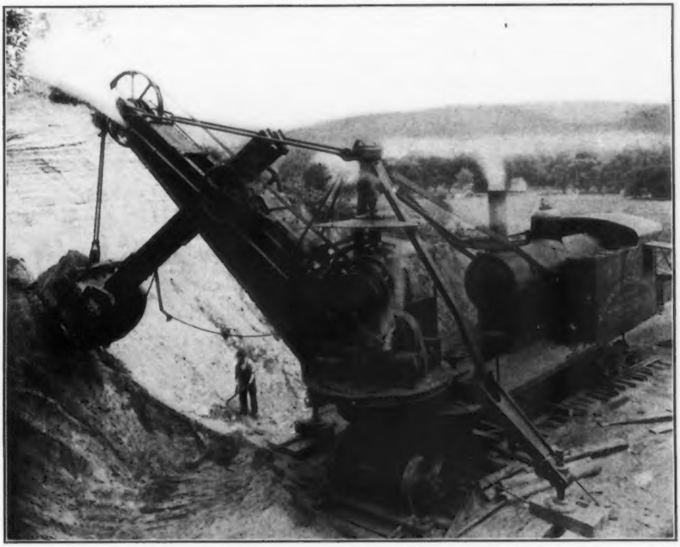


FIG. 5.

and irregular work. The American machine, capable of exerting a pull of 40 000 to 60 000 lb. on a single large and strong bucket, can do more effective work in hard material than a chain of buckets which are necessarily lighter individually and of less power. Also the American shovel is flexible and works on temporary rails laid on uneven ground, while the European machine requires a fairly well-laid track of five rails. As to capacity, the rate is the same whether we use a single bucket of 2.5 cu. yd. four times per minute, or a chain of buckets 0.75 cu. yd. thirteen times per minute, with the advantage in simplicity and lightness in favor of the single bucket. On the other hand, the European machine can stand on top of the bank and dig below its own level, while the American machine must stand on the bottom of the cut.

The British type of shovel is called a "Steam Navvy" and is of two kinds, the first having a dipper mounted on a revolving steam crane, and the second a dipper mounted on a swinging crane attached to a stationary car. In both of these types a single pair of engines is made to perform all the operations by means of clutches, a method now obsolete in America, and the machines are of small power and slow speed. Also the British machines are mounted on four rigid wheels. The writer thinks two trucks of eight wheels, as in American practice, much more flexible and better adapted to uneven temporary track giving less concentrated load.

Reviewing the steam shovel, it may be said that it has practically doubled in size in the past decade, keeping pace in this respect with the dipper and hydraulic types of dredge. Any great further increase in size does not appear probable until larger and stronger cars are used to receive and carry away the material. Cars 40 ft. long and of 100 000 lb. capacity are now used as ballast cars, and these only on fairly good track. For conditions in which light and frequently shifted track is necessary, small cars of 5 to 10 cu. yd. capacity each will continue to be used, and therefore a limit put upon the size of shovel. For ordinary work, therefore, a dipper of 2.5 cu. yd. for a 5-yd. car and 3.5 cu. yd. for the larger cars appears to be most desirable. Shovels of 100 tons weight and with 5-yd. dipper have been built, but as yet it is doubtful if the increased power and capacity obtained compensates for the loss in speed and for the increased difficulty of providing cars of the necessary size and strength.



WIRE-ROPE SHOVEL AT WORK ON THE NEW YORK CENTRAL AND HUDSON RIVER RAILROAD.

In point of efficiency and better design much has been done, but there is still much room for improvement. The unusual demand for shovels during the past three years has furnished a market for anything in the shape of a shovel, but with a slacker demand and more competition a better standard of design and workmanship will prevail. No machine in the world is subject to harder and rougher service, and as a rule is as little cared for, consequently a certain amount of wear and interruption is to be looked for, but at present the majority of breakdowns are due to preventible causes. Competition between the builders to produce a low-cost shovel has been responsible for much lack of excellence. Intelligent users now realize that the best is none too good, and naturally costs more at first, but less in maintenance.

The writer has endeavored to indicate the lines on which progress is being made in dredging and excavating machinery in America, and to place on record his impressions of the present state of the art. The subject is a wide one and much has doubtless been omitted. Compared with the locomotive, the steamship, or other engineering lines of wider application, this art is backward. This is due to the fact that a comparatively small number of dredges are required, and under such diverse conditions that two are seldom alike. Thus development is slower than is the case where thousands of examples are being built, and many minds are gathering data and concentrating their efforts. Great as are the results now obtained, the next decade will witness a greater ratio of improvement. The transition from the early pioneer methods to the larger and more powerful appliances of the skilled engineer has begun, and the growing wealth of nations furnishes at once the financial means and the commercial necessity for the accomplishment of transportation projects hitherto deemed impossible. The improved development, therefore, of the machines described in this paper is of vital importance in making it possible for works of magnitude to be done quickly and cheaply, and in opening up the avenues of trade and commerce throughout the world.

TRANSACTIONS

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

Paper No. 39.

DREDGES: THEIR CONSTRUCTION AND PERFORMANCE.

DREDGING OCEAN BARS.

By J. C. Sanford, Maj., Corps of Engrs., U. S. A.

In his excellent review of the progress made during the past ten years in all classes of dredges, A. W. Robinson, M. Am. Soc. C. E., considers four types of the hydraulic or suction dredge. The present paper will have to do mainly with the first of these types, namely, the sea-going, hopper type, without anchorage, and will consider particularly the development of this type within the past twenty years in the United States.

This development has resulted from experience and repeated failures in attempting to use on ocean bars and in other exposed localities dredges of the dipper or grapple type, with auxiliary plant for the removal of material dredged. In every such case, as far as known, the result has been either that the various pieces of floating plant have been soon worn out or destroyed by pounding against each other, or that, in endeavoring to avoid such injuries by working only in very quiet weather, the work has been excessively slow and costly.

The earliest dredge of this type used in the United States was, it is believed, the *Gen. Moultrie,* used in 1855 at Charleston, S. C., in the Beach Channel, leading from the ocean to the harbor. This dredge is stated to have been a moderate sized commercial steamboat, converted into a dredge by the addition of centrifugal dredging pumps, with necessary piping, etc., and with bins constructed in the hold. Her drags, or suction heads, were probably somewhat similar to those now in use. While her capacity was small, her manner of working was practically the same as is now followed, and the location of her work was, except for a rather deeply submerged bar on the ocean side, exposed to the full force of the sea.

In 1875 a side-wheel steamboat was purchased by the Government and converted into a dredge under direction of the late General Q. A. Gillmore, M. Am. Soc. C. E., Corps of Engineers, U. S. A., for use in the Savannah River, Ga., and at other points on the South Atlantic Coast. This dredge was called the *Henry Burden* and is fully described in the "Annual Report of the Chief of Engineers" for 1875, Part 2, Appendix U 3. She continued in service for about ten years.

In 1878 it was decided to improve the entrance to Charleston Harbor, S. C., by means of two converging jetties, the action of which in deepening the Swash Channel across the outer bar it was proposed to assist by dredging. The first of the two jetties was begun in the same year. During the construction of these jetties, a large amount of dredging on the outer bar was done, both by contract and afterward by the Government dredge *Charleston,* constructed in 1890. The price paid under the first of these contracts was 30 cents per cu. yd. The contractor used at first a suction dredge which was not self-contained; and the dump scows which were used with her, practically pounded her to pieces. Under the second contract the contractor used the hull of a schooner altered into a self-contained, but not self-propelling, suction dredge, a tugboat being used to tow it in and out across the bar.

None of the dredges used before 1890 produced great results in channel deepening or did work at what would now be considered a low unit cost. Nevertheless they proved clearly the advantage of the self-contained, self-propelling type for work in water even moderately rough. From 25 cents to $1.00 per cu. yd.

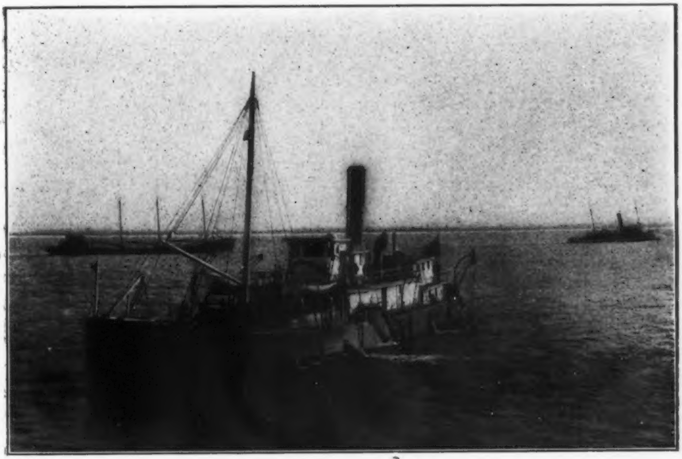


FIG. 1.—U. S. DREDGE "CAPE FEAR."

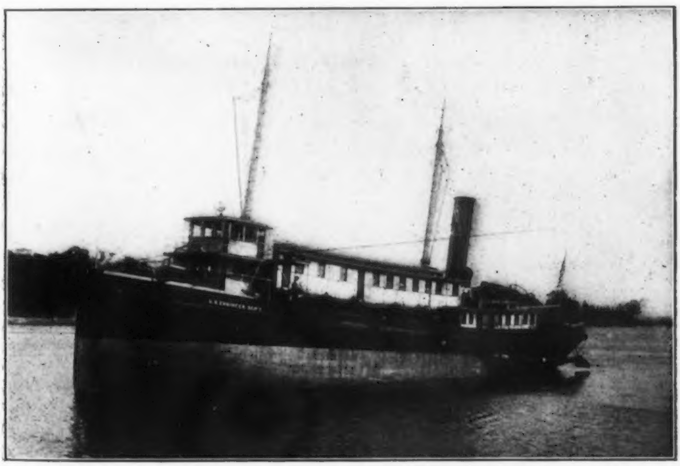


FIG. 2.—U. S. DREDGE "C. B. COMSTOCK."

for material dredged, according to locality and amount of work, was still considered a fair price for dredging on ocean bars; and, on account of the great cost of dredging, the plan of deepening these bars by scour produced by jetties was regarded as the only practicable one.

In 1880 the necessity of deepening the entrance channel to New York Harbor became urgent, due to rapid increase in draft of the vessels using it. Very complete surveys were made, with extensive current and tidal observations, for the purpose of basing on the results a project for producing and maintaining an entrance depth of 30 ft. at mean low water. Several tentative projects for permanent works, with a view to getting these results, were framed, but were all found to be either too expensive or to present serious objections, from engineering or navigation standpoints; and it was finally decided to deepen first the existing main channel by dredging with a view to determining by experience whether or not the required depth and width could be provided and maintained at reasonable cost by this method. The dredging to be done was partly through the main or outer ocean bar (Gedney's Channel), and partly through the Main Ship Channel, inside of Sandy Hook. At the former locality, the material to be removed was mainly coarse sand and gravel, and, in the latter, mud and fine sand, much of the mud being extremely soft.

In 1884 Congress made the first appropriation for this work, the project contemplating a width of 1 000 ft., with the above-mentioned depth of 30 ft. Table 4 shows with whom contracts were made, the amount and location of dredging, cost, etc.

Work was commenced on the first contract on September 26th, 1885, and the work on the last contract was completed on October 10th, 1891, covering a period of six years and fourteen days. The material removed was composed largely of gravel and coarse gray sand. From Table 4 it is seen that the greater part of the work was done by the Joseph Edwards Company. Some of the dredges used by this company were the *Reliance,* the *Advance* and the *Mount Waldo.*

The hull of the sea-going dredge *Reliance* was of wood. Her dimensions were as follows:

Length	157 ft.
Beam	37 ft.
Depth of hold	16 ft.

Twin compound engines (15 + 26 by 22 in.) each 350 i. h. p.

Two Scotch boilers (11 by 12 ft.), 80 lb. working pressure.

Two 15-in. Edwards pumps, belt-driven by single horizontal condensing engines of about 100 h. p.

The carrying capacity of the dredge was about 650 cu. yd. per load. The average number of loads per day on the work was 3; the distance from the work to the dump was about 12 miles. (This dredge was purchased by the United States Government in 1892, and renamed the *Gedney*. She has since been used in the maintenance of the New York Harbor channels.)

The dredge *Advance*, also built of wood, was of the following dimensions:

Length	132 ft.
Beam	39 ft.
Depth of hold	8 ft.
Propelling engine	1
15-in. pumps, Edwards	2

The carrying capacity of this dredge was about 500 cu. yd.

The wooden dredge *Mount Waldo* was of the following dimensions:

Length	145 ft.
Beam	31 ft.
Depth of hold	11 ft.
Propelling engine	1
15-in. pumps, Edwards	2

The carrying capacity of this dredge was 275 cu. yd.

Since the completion of this work the cost of maintaining the dredged channel to full width and depth has been found to be very moderate.

TABLE 4.

Contractor.	Date.	Place.	Requirements.	Cubic yards removed.	Price, per cubic yard.	Amount.
Roy Stone..............................	February 7th, 1885.	Gedney's Channel.	200 ft. wide, 28 ft. deep.	None	33 cents.	....
Elijah Brainard..........................	July 31st, 1885.	"	320 000 cu. yd.	303 896	54 "	$164 103.84
Joseph Edwards Dredging Company.	April 27th, 1887.	"	700 000 cu. yd.	770 410	28.5 "	211 016.85
"	May 19th, 1887.	Main Ship Channel.	1 500 000 cu. yd.	1 305 202	28.5 "	371 982.57
Brainard Bros........................ ...	May 11th, 1888.	"	200 000 cu. yd.	200 000	28.5 "	57 000.00
Joseph Cummings......................	May 11th, 1888.	"	800 000 cu. yd.	None	28.5 "	....
Joseph Edwards Dredging Company.	December 15th, 1888.	Gedney's Channel.	600 000 cu. yd.	599 362	17 "	101 891.54
Brainard Dredging Company.........	November 26th, 1889.	Main Ship Channel.	1 000 000[a] cu. yd.	71 325	$16\frac{7}{8}$ "	12 036.09
Joseph Edwards Dredging Company.	March 22d, 1890.	"	[b]Done on Brainard's contract.	169 754	$16\frac{7}{8}$ "	28 654.98
"	March 18th, 1890.	"	425 000 cu. yd.	425 000	23.5 "	99 875.00
"	August 13th, 1890.	"	530 000 cu. yd.	530 000	22.6 "	119 780.00
"	February 16th, 1891.	"	500 000 cu. yd.	500 190	23.9 "	119 531.07

Total number of cubic yards removed.............................. 4 875 079.

Average price per cubic yard.. 26.4 cents.

Total cost of the work.. $1 285 862.94.

[a] Brainard Dredging Company withdrew from this contract on April 16th, 1890.

[b] Joseph Edwards Dredging Company withdrew from work under this contract on June 18th, 1890, and the contract was annulled.

SEA-GOING DREDGES CONSTRUCTED BY THE UNITED STATES GOVERNMENT, 1890 TO 1900.

Owing to the fact that no contractor owned dredges adapted to rapid and economical work on ocean bars, nor could afford to construct dredges of this expensive class unless assured of practically continuous work for them, it was decided about 1890 that, in order to prosecute vigorously the dredging work contemplated in connection with the Charleston Harbor jetties, it would be advisable for the Government to construct a sea-going, self-contained, self-propelling dredge of considerable capacity, which would be well adapted also for maintaining the channel after it should be once formed. The dredge was built in 1890 and named the *Charleston.* She was of light draft, was adapted to working in a moderate sea, and had a bin capacity of about 340 cu. yd. She had one dredging pump only, with 15-in. diameter suction and discharge. In designing her, the importance of minimizing the loss of time in going to and from her dumping point was considered, as well as the importance of giving her as great a capacity as was practicable within the limits of available funds. As a result of these considerations she was given a speed of about 9 knots. At that time it was expected that the locality in which she would work would, at all times, be protected to some extent from seas by the jetties during their construction. In 1899 an excellent channel had been produced between the jetties, but a portion of the material scoured out by them had deposited outside of their outer ends to such an extent as to form a troublesome bar. Whenever weather permitted, the *Charleston* was utilized in maintaining the channel over this bar; but, owing to her low freeboard, she could only work there in fair or moderate weather. As it was then expected that most of her future work would be on this very exposed bar, she was rebuilt and a second deck added, thus giving her greatly increased freeboard, though with consequent increased draft.

While she was being rebuilt, the channel which she had endeavored to maintain and which was quite unfavorably situated for maintenance, as it was on the side of the bar toward which the resultant movement of the sand was taking place, deteriorated badly, and the line of deepest water was deflected so much that the main entrance range could not be followed by vessels. A comparison of

TABLE 5.

	Gedney.	Charleston.	Cape Fear.	Comstock.	Winyah Bay.
Length over all, in feet	161	$122\frac{1}{2}$	$131\frac{1}{4}$	177	141
Length between perpendiculars, in feet	150	$112\frac{1}{2}$	127	165	$132\frac{5}{12}$
Beam, moulded, in feet	$36\frac{1}{3}$	$29\frac{1}{2}$	$28\frac{1}{2}$	35	$30\frac{2}{3}$
Depth, moulded, in feet	21.6	$20\frac{1}{2}$	17	16	13.6
Draft, light, in feet	16	$11\frac{1}{6}$	$13\frac{1}{3}$	13	$8\frac{1}{2}$
Draft, loaded, in feet	19	15	$15\frac{1}{4}$	14	$12\frac{3}{4}$
Bin capacity, in cubic yards	735	340	295	639	306
Number of propelling engines	2	1	1	1	1
Size of propelling engines	$\frac{15\text{–}26}{22}$	$\frac{17\text{–}32}{22}$	$\frac{15\text{–}30}{24}$	$\frac{20\text{–}36}{36}$	$\frac{17\text{–}32}{26}$
Horse-power of each engine	350	500	288	550	450
Number of dredging pump engines	2	1	2	2	1
Size of pump engines	15 by 20	$\frac{13\text{–}23}{14}$	$10\frac{1}{2}$ by $10\frac{1}{2}$	$\frac{15\text{–}24}{14}$	$\frac{12\text{–}22}{14}$
Horse-power of each pumping engine	100	250	....	125	240
Number of pumps	2	1	2	2	1
Size of pumps, in inches	15	15	10	15	15
Number of boilers	2	1	1	2	1
Size of boilers	11 ft. by 12 ft. 3 in.	12 ft. by 13 ft.	10 ft. 6 in. by 11 ft. 8 in.	10 ft. by 11 ft.	13 ft. 6 in. by 12 ft.
Type of boilers	Tubular	Scotch	Scotch	Scotch	Scotch
Working pressure, in pounds	80	110	100	100	125

the various surveys of this bar indicates that it was mostly, if not wholly, caused by the deposit of material scoured from between the jetties, and that the resultant movement of the sand composing it was in a direction making an angle of about 25° with the entrance range. The bar was pear-shaped, with its base and highest portion parallel to the entrance range, and its stem joining the beach behind the north jetty. In May, 1900, it was decided to open a channel through this stem, as it was believed that the bar was not being added to from the north, whereas it was known that the resultant drift of the bar was in a southerly direction. At the point where it was proposed to cut the channel, there was a least depth of 15.9 ft. at mean low water, whereas in the crooked channel south of the bar there was a depth of about 18.5 ft. The work of the *Charleston* since May, 1900, on this new channel has not been continuous, as she has been sent at times to other harbors where emergency work was needed. Surveys show that during such absence the new channel had not deteriorated. On the other hand, the total quantity of material which had been removed by the dredge and by the tidal currents from this new channel during the past four years, was shown by a recent survey to have been 50% more than was actually removed and dumped by the *Charleston*. The channel has now a depth of 27 ft. at mean low water, and a good and constantly increasing width. This dredge has lost, on account of stormy weather since her rebuilding, but a very small percentage of the total working days. The cost of producing and maintaining the new channel has not been greater than would have been the cost of maintaining the unsatisfactory, comparatively shallow channel on the south side of the bar.

The successful work done by the *Charleston* from the time she was originally constructed has led to the building of a number of similar dredges for the improvement and maintenance of various harbors on the Atlantic and Gulf Coasts. All those constructed up to 1900 were given a similar amount of freeboard, as it was not then considered that work could be accomplished upon an ocean bar during storms. Table 5 contains data regarding all the dredges constructed by the Government in this period; also of the somewhat similar dredge *Gedney*, purchased by the Government in 1892.

Figs. 1 and 2, Plate XXIV, show typical dredges of this class.

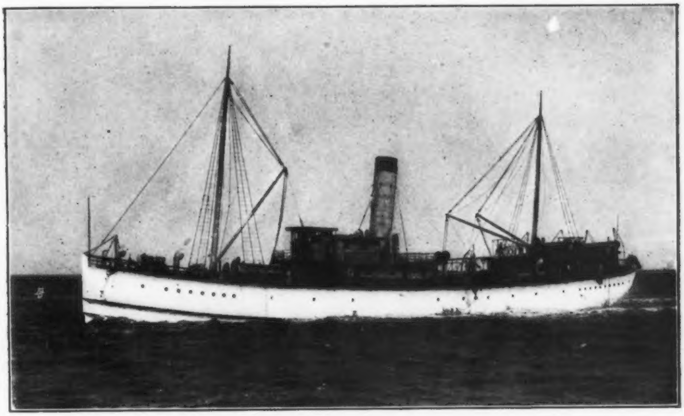


FIG. 1.—U. S. DREDGE "CUMBERLAND."

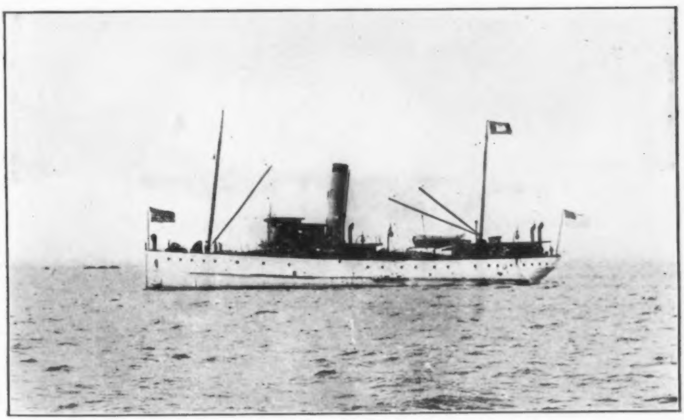


FIG. 2.—U. S. DREDGE "BURTON."

Sea-Going Dredges Constructed, or Under Construction, by the United States Government, 1901 to September 1st, 1904.

The results obtained in the operation of the dredges already described, proved that, by the use of such dredges, channels could be readily deepened across ocean bars at a cost per cubic yard which compares very favorably with the cost of contract dredging in the most sheltered locations, and where all other conditions are conducive to economical work; also, that the channels thus obtained could, in nearly all localities, be maintained at moderate cost by such dredges. This has led to a decided change of view on the part of many engineers as to the necessity for constructing expensive permanent works for the purpose of deepening channels over ocean bars. For many localities it is believed that the proper functions of jetties should be simply to protect and maintain a channel after this channel has been produced by dredging. For many other localities, where the littoral movement of sand is comparatively small, it is believed that no jetties at all are required, as a channel can be produced and maintained by dredging at a cost far less than that of constructing and maintaining jetties.

Where the littoral movement of sand is very great, jetties or a single jetty, may be necessary; but it is the opinion of the writer that even in such locations the jetties should be designed so as to give little or no contraction across the bar. The results of too great contraction are plainly seen in the bar which has formed outside the Eads jetties at the South Pass, Mississippi River, in the outer bar at Charleston, and in the necessity of continually extending the parallel jetties of the Great Lakes' harbors, or of doing each year a constantly increasing amount of dredging.

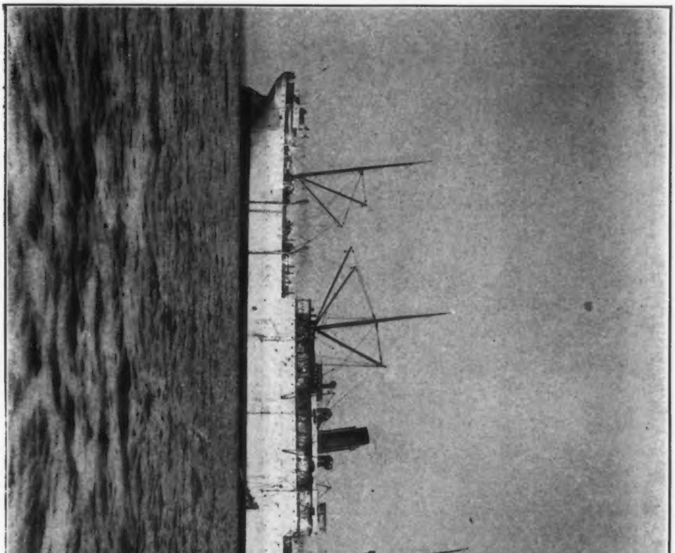
In 1898, in accordance with the requirements of a Congressional resolution, a project was prepared and subsequently approved providing for securing an entrance channel to Charleston Harbor not less than 26 ft. deep at mean low water. This project provided for building a large sea-going dredge having a capacity of not less than 4 000 cu. yd. per day, and for working it in conjunction with the dredge *Charleston*. The estimated cost of the proposed dredge was $150 000. There seemed to be some doubt at the time as to whether or not a channel could be maintained by dredging. The project had provided for operating the dredges three years, and it

was added, "if, by the end of that time, it was found that the depth of 26 ft. could not be maintained, the jetties could be extended." Plans for the proposed dredge were made and proposals for its construction called for; but, on account of the high prices of material and labor at that time, the lowest bid far exceeded the authorized cost. In 1900, under somewhat modified plans, proposals for constructing such a dredge were again called for. The lowest bid being satisfactory in amount, the construction was begun, but was attended with an excessive and unusual amount of delay, so that this dredge was not completed until 1904. In the meantime the small dredge *Charleston*, as has already been described, produced a somewhat greater depth than was contemplated in that project, and had maintained the depth and gradually increased the width without difficulty. The new dredge, known as the *Gen. Abbot*, is briefly described as follows:

Length over all	200 ft.
Length between perpendiculars	185 "
Beam, moulded	40 "
Depth, moulded	20 "
Bin capacity	about 1 000 cu. yd.
Propelling engines	one 22 by 44 by 30-in.
Boilers	two 14 by 12-ft., by 125 lb.
Pumping engines	two 12 by 22 by 15-in. direct-connected to 18-in. dredging pumps.

The material of the hull is wood. Owing to the increasing scarcity of the larger sizes of timber suitable for ship construction, it is not believed that dredges larger than the *Gen. Abbot* will hereafter be constructed of wood. This material was selected for this dredge, however, on account of its superior elasticity—an important consideration in the case of dredges intended to work in rough seas and shoal water where they must frequently pound on bottom—and on account of the greater ease of repairs, particularly in a section of country devoid of large shipbuilding plants. The *Gen. Abbot* is similar in most respects to the *Charleston* as rebuilt, but much larger, her bin capacity being about three times as great.

In 1901 a dredge, almost identical with the *Gen. Abbot*, was planned for improving the entrance to Cumberland Sound, Georgia



U. S. DREDGE "CHINOOK."

and Florida, on which the Port of Fernandina is situated. The construction of this dredge proceeded much more rapidly than did that of the *Gen. Abbot,* and she was completed before the end of 1902. She has since been doing very efficient work at the harbor for which she was built, as well as in the Savannah River and in the Delaware River. Her best record is about 8 300 cu. yd., removed during one daylight from the Cumberland Sound bar and dumped at a distance of about 1 mile. The material was coarse sand mixed with shells. This dredge is shown by Fig. 1, Plate XXV.

In the *Gen. Abbot* and *Cumberland,* a new feature was introduced to enable them to work in depths less than their maximum loaded draft, and the same feature has been embodied in the plans of all the dredges since constructed or now under construction by the Government. This consists in providing overflows at two different levels, so that the dredge can be loaded to the level of the lower overflow and no water carried in the bins above this level, if desired. It is in this way that the *Cumberland* has been obliged to work in the Delaware River. When working in this manner she carries about half the maximum load. The material in which she has worked in the Delaware has been extremely soft mud, only a part of which could be made to settle in her bins; nevertheless, her average dredging in August, 1904, has been about 4 000 cu. yd. in 12 hours, the average distance to the dump being $1\frac{1}{2}$ miles.

In 1902 a project was prepared for obtaining a channel 40 ft. deep at mean low water over the bar outside the mouth of the Columbia River, Oregon and Washington, where the existing depth was about 22 ft. This is probably the most exposed bar on any of the coasts of the United States. During storms the waves break heavily over the entire 8-mile length of the bar. The littoral movement of sand along this coast is also very great.

In the hearings and discussions preliminary to the preparation of a project, the opinion was expressed by many experts that no dredge, whatever its construction, could work on this bar during more than a small portion of the favorable season of the year. It was generally considered that it would be useless to attempt it with a dredge of small or even moderate sized hull. To construct a dredge with a hull not less than about 400 ft. in length

would take too long a time, and its cost would be greater than the Board which prepared the project, thought advisable to devote to what might prove an unsuccessful experiment. About this time a number of large steamships belonging to the Army Transport Service had been placed out of commission at San Francisco, Cal., and it was thought that, if one of these of large tonnage and not of great draft could be transferred to the Engineer Department and converted into a dredge, the question as to the possibility and practicability of dredging on the Columbia River bar could be determined without too great cost or delay. The matter having been brought to the attention of the Quartermaster General, it was decided that the transport *Grant* should be transferred for this purpose. The *Grant*, formerly the S. S. *Mohawk*, of the Atlantic Transport Line, was built in Belfast, Ireland, in 1892. Her hull is of steel. The following are her principal dimensions:

Length	445 ft.
Breadth	49 "
Depth of hold	34 "
Draft, light (before alteration)	16.8 "
Draft, loaded "	25.3 "
Gross tonnage	5 590 tons.
Net tonnage	3 604 tons.

It was realized by the Board that her large draft would seriously inconvenience her, as, until the bar should be somewhat deepened, it would be impossible for her to work on it at low water; but it was believed that this inconvenience would not be of very long duration. The work proposed to transform her into a dredge consisted of building two large sand bins having a total capacity of 3 600 cu. yd. in what had been her cargo spaces; of constructing and installing two 20-in. dredging pumps and appurtenances (with a view to increasing the pumping plant subsequently if found advisable), and of removing the auxiliary machinery, such as refrigerating, ice-making and ventilating machinery, which was not needed for her proposed service. Only such changes were to be made in the arrangements of her quarters, etc., as were absolutely necessary, as it was considered important to restrict, as far as possible, the cost and time of the work.

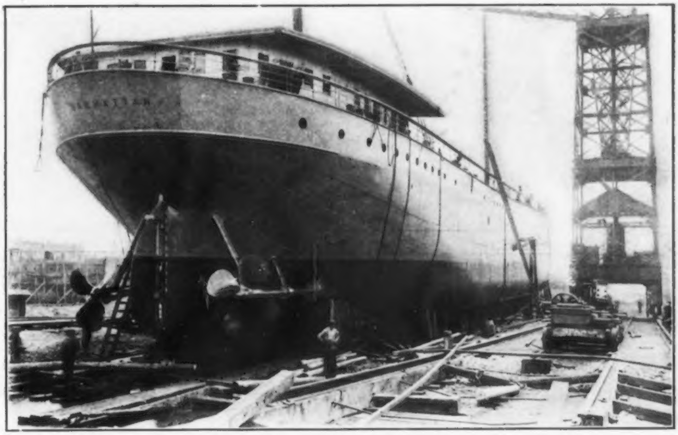


FIG. 1.—U. S. DREDGE "MANHATTAN," READY TO LAUNCH.

FIG. 2.—U. S. DREDGE "KEY WEST," UNDER CONSTRUCTION.

Her transformation was begun in the latter part of February, 1902, at Mare Island Navy Yard, California, and would have been completed in July of that year, or at latest in August, had the contractor for constructing the dredging pumps not been greatly delayed with his work. As it was, she was completed ready for service in the latter part of October and arrived in the Columbia River on November 2d. (Her name had been changed to the *Chinook*.) The rainy season, which is also a season of almost constant storms and fogs, had already begun, however, and during this season but little dredging work was practicable. By working on the bar at her normal rate during a storm, when two fairly large steamships lay in the mouth of the river not daring to attempt the crossing of the bar, she demonstrated that she could work in very severe weather.

During the rainy season many more or less important improvements were made in her machinery. Since the beginning of the summer season she has done fairly good work, though her draft has been a decided drawback. The question as to whether dredging will be of great advantage prior to the completion of the jetty now in progress, appears to be still unsettled, but the possibility of dredging on this bar, with a dredge specially adapted to it, has been fully determined. Plate XXVI is a photograph of this vessel after being transformed into a dredge.

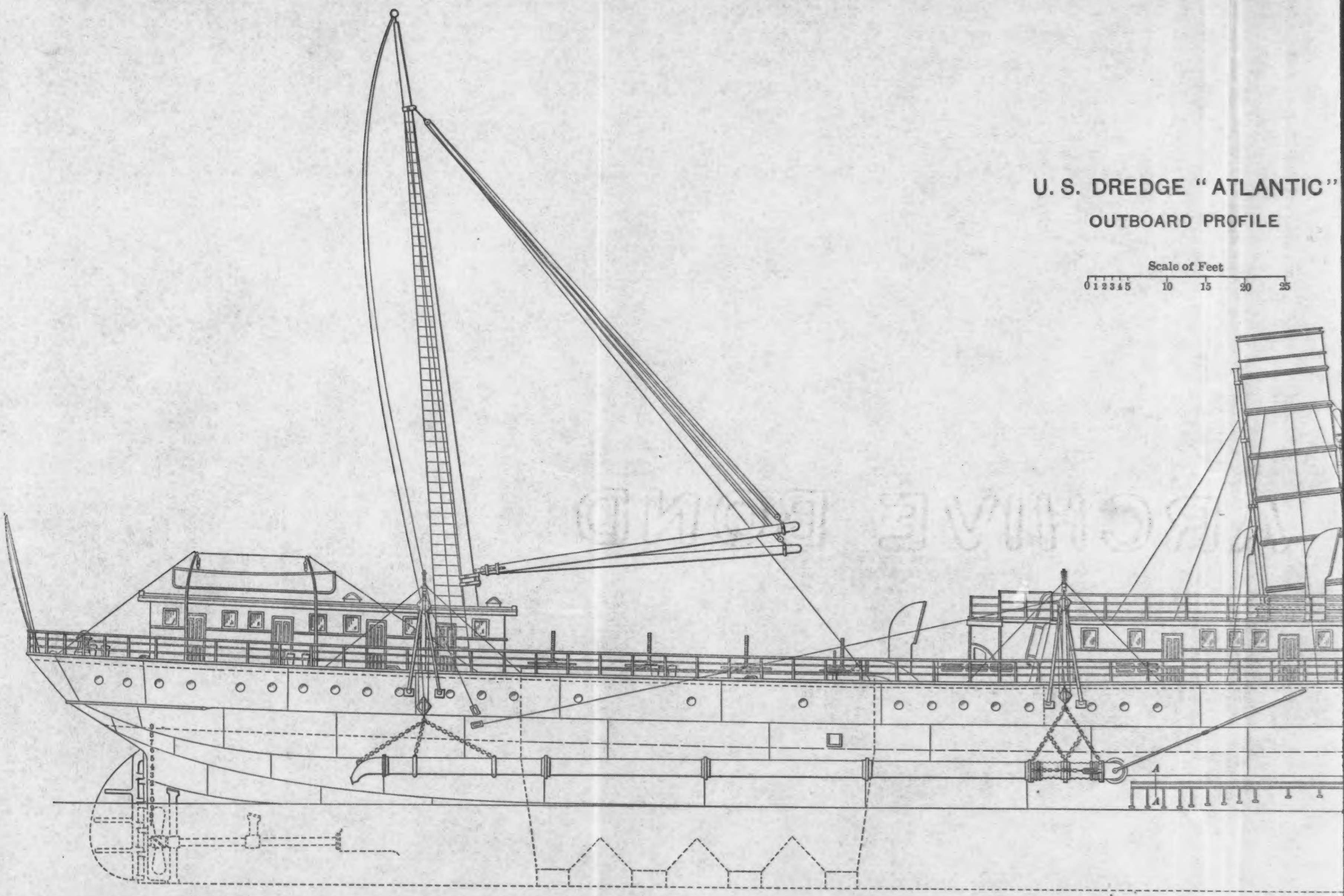
For improving the Southwest Pass of the Mississippi River, with a view to giving a channel 1 000 ft. wide and 35 ft. deep at mean low water, from New Orleans to the Gulf of Mexico, two converging jetties across the outer bar are contemplated (the construction of one of these has been begun), the action of the jetties to be assisted by a large sea-going suction dredge. The dimensions of this dredge are as follows:

Length between perpendiculars..........	260	ft.
Length over all......................	271½	"
Moulded beam	47½	"
Moulded depth	23	"

She is of steel and has twin-screws. She was begun at the yard of the Trigg Shipbuilding Company, Richmond, Va., in 1901, and was completed at the Norfolk Navy Yard, Norfolk, Va., on account

of the failure of the Trigg Company, and sailed for New Orleans in September, 1904. At the time the contract for her construction was made, no dredge had been constructed or planned by the Government having more than about one-half her bin capacity. She will be exceeded in size, however, by the dredges *Manhattan* and *Atlantic*, the former of which is practically completed and the latter nearly so. Her dimensions are also greatly exceeded by those of the proposed dredge for the Delaware River.

Between 1884 and 1899 the size of steamships entering New York Harbor had increased so greatly that the 30-ft. entrance channel was deemed inadequate, both in depth and width, for their accommodation. Moreover, the sharp turn in the Main Ship Channel was inconvenient, and dangerous in thick weather. Accordingly, Congress, by Act of March 3d, 1899, adopted a project for making a channel 2 000 ft. wide and 40 ft. deep at mean low water, from the Narrows to the sea, by way of East or Ambrose Channel, at a limit of cost of $4 000 000. The channel was to be obtained by dredging only. The quantity of material to be removed was estimated at 42 500 000 cu. yd. The natural depth on the crest of the bar was about 16 ft. The contract for all the work, approved May 24th, 1899, provided for beginning work on May 24th, 1900. Soon after the approval of the contract, the construction of two immense sea-going, self-contained, self-propelling dredges was begun by the contractor. The completion of both of these, however, was delayed so long that the time for beginning work was extended about one year. Each of these dredges, called the *Mills* and the *Thomas*, respectively, has a bin capacity of about 2 800 cu. yd. and one 48-in. dredging pump. Each has one suction pipe which is raised and lowered through a well on the center line of the ship. They do not keep in motion while dredging, as in the case of all the Government sea-going dredges thus far constructed, but work with stationary suctions, hauling themselves by anchors and chains when necessary to move. Their dredging capacity is large—for example, in July, 1904, they removed 400 125 cu. yd. of sand and gravel—but their draft is excessive with regard to the natural depth on the bar. In consequence of this, while they had removed, to the end of July, 1904, 12 344 266 cu. yd., all their work has been done between the 40-ft. contour line outside the bar and its crest, so that the ruling depth



U. S. DREDGE "ATLANTIC"
OUTBOARD PROFILE
Scale of Feet
0 1 2 3 4 5 10 15 20 25
A
A

U. S. DREDGE "ATLANTIC"

OUTBOARD PROFILE

Scale of Feet
0 1 2 3 4 5 10 15 20 25

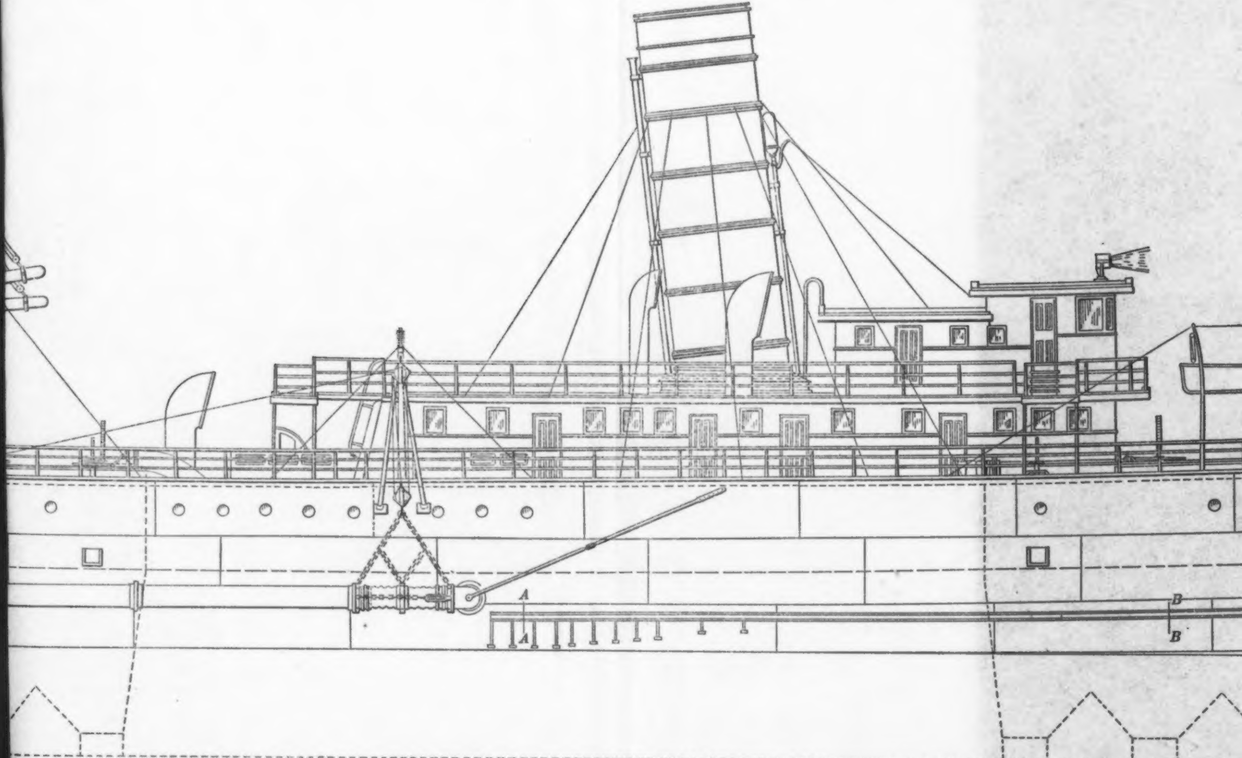
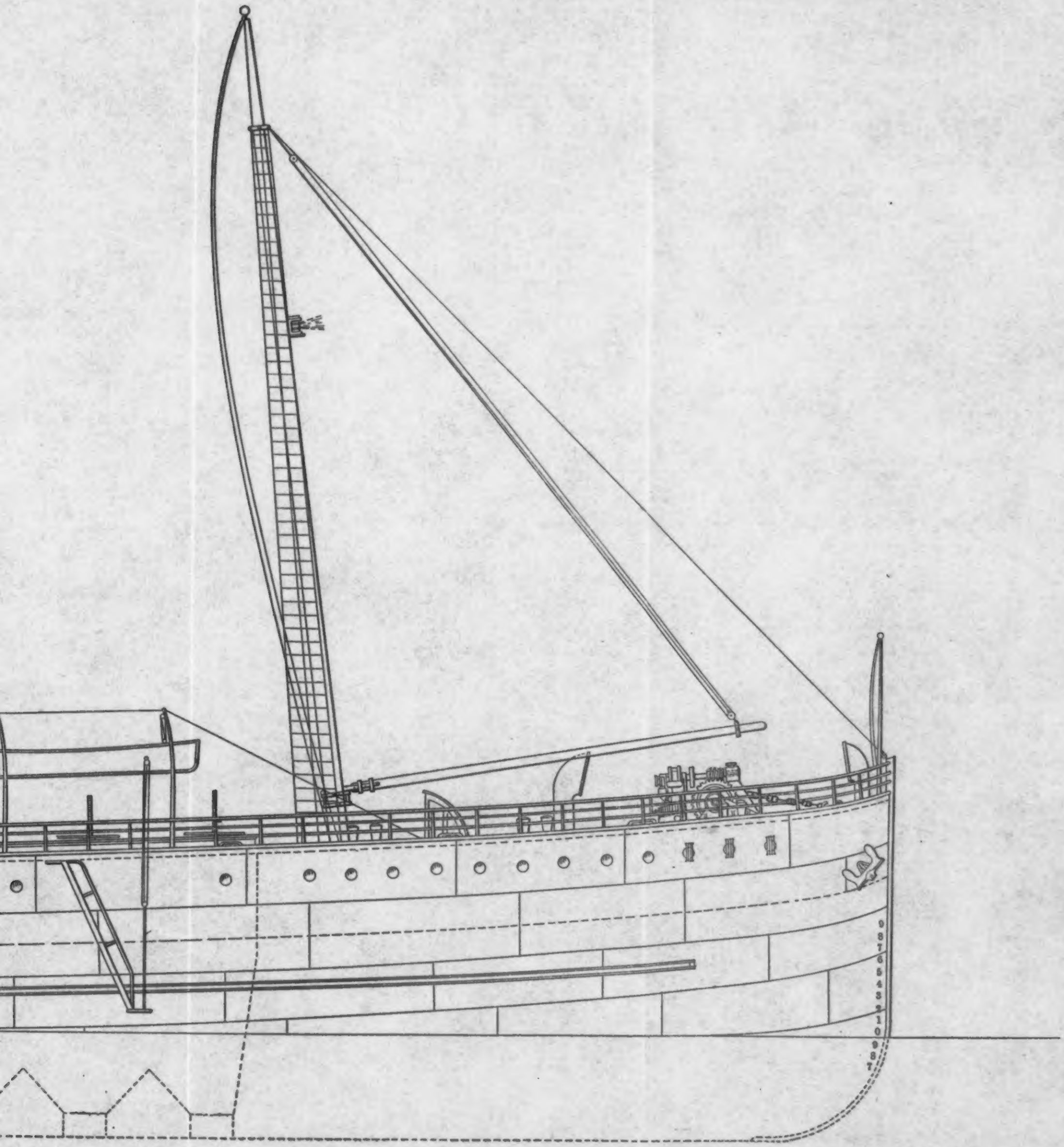


PLATE XXVIII. VOL. LIV. PART C.
TRANS. AM. SOC. CIV. ENGRS.
INTER. ENG. CONG., 1904.
SANFORD ON
DREDGING OCEAN BARS.



through the channel is still about 16 ft. The dredging produces conical holes having frequently a center depth as great as 54 ft., with ridges between.

With easily moved material and strong tidal currents, it might have been expected that Nature would level these ridges; but, thus far, very little of this effect has been noticed on this bar, the material being heavy and the currents only moderate. By the foregoing method of work the deductions for over-depth are naturally large, and it is estimated that, of the 12 344 266 cu. yd. dredged, only 10 552 338 cu. yd. were from within the channel limits of depth. These dredges embody many of the general features of the *Brancker* and the *Crow,* which have done very successful work on the bar at the mouth of the Mersey River, England; but do not seem to be as well adapted to the conditions found on the New York bar.

Using the foregoing dredges only, the contractor has not been able to obtain as great an average monthly rate of dredging as that required by the original contract. At his request, a supplemental agreement was entered into, reducing the monthly requirements, but permitting the Government to accelerate the work by the use of additional plant which it may own, rent or build for the purpose. The necessity for hastening the work being urgent, it was decided by the Engineer Department, in 1903, to construct two large sea-going dredges, on plans similar to those of the dredge then being constructed for improving Southwest Pass, Mississippi River, which has been described previously. A somewhat larger limit of cost, however, was allowed, so that the hulls of these dredges might be given better lines with consequently increased speed for the same power. Mechanism for opening and closing the dumping gates by steam power was also provided.

The first of these, the *Manhattan,* was launched on July 9th, 1904, has had her official trials, and will soon begin operations at New York. The second, the *Atlantic,* was launched on August 20th, 1904. The two are precisely alike in every respect.

The construction of six other dredges was also begun by the Government in 1903. These are the *St. John,* for improving St. John's River, Fla.; the *Caucus,* for improving Pensacola Harbor, Fla.; the *Burton,* for improving harbors on the south shore of Lake Erie; the *Gen. Gillespie,* for improving harbors on the east shore of

Lake Michigan; the *Savannah*, for improving Savannah Harbor, Ga.; and the *Key West*, for improving Key West Harbor, Fla.

Two of these, the *Burton* and the *Gen. Gillespie*, have since been completed, and the *St. John* and *Key West* are nearly completed. The *St. John* and *Caucus* are wooden, single-screw dredges, quite similar to the *Gen. Abbot* and *Cumberland*. The *Burton* and *Gen. Gillespie* are steel, twin-screw dredges of light draft, designed for work in fresh water and in the narrow channels of the Lake harbors. They are of slightly less capacity than the *Gen. Abbot* and *Cumberland*. The *Savannah* is similar to the *Burton* and *Gen. Gillespie*, except that she was designed for work in salt water. The *Key West* is a small, light-draft, wooden dredge, similar to the *Winyah Bay*, though with more freeboard. (The latter dredge has proved extremely serviceable at points where very light draft was essential, but, on account of her low freeboard, much time was lost while working in exposed localities.)

Experience has shown that dredges of this class are not only by far the best adapted of all known types for work on exposed ocean bars, but possess marked advantages for the maintenance of channels dredged in rivers or other sheltered waters. These advantages are: First, they can be operated economically in the removal of shoals of slight depth; second, they offer no obstruction to navigation, as they can get out of the way of other vessels quickly without interfering with their own work; third, the improvement in depth obtained by them is progressive, the shoal being removed from the top and not from the end. On account of this method of deepening, also, the assistance of the currents in producing scour is obtained more quickly. Based on these considerations, the Secretary of War, in December, 1903, decided to make an allotment for the construction of a large, self-contained, self-propelling dredge for the maintenance of the channel of the Delaware River. This channel is now being deepened to 30 ft. at mean low water for a width of 600 ft., and, as each of the nine sections into which the length of the proposed channel is divided, is completed by the contractor, the maintaining of the channel in these sections devolves upon the Government. The total length of dredged cuts will be 32 miles, of which about 14½ miles will have been completed by the end of the season of 1904.

The allotment for the construction of this dredge was $400 000,

U.S. DREDGE "ATLANTIC"

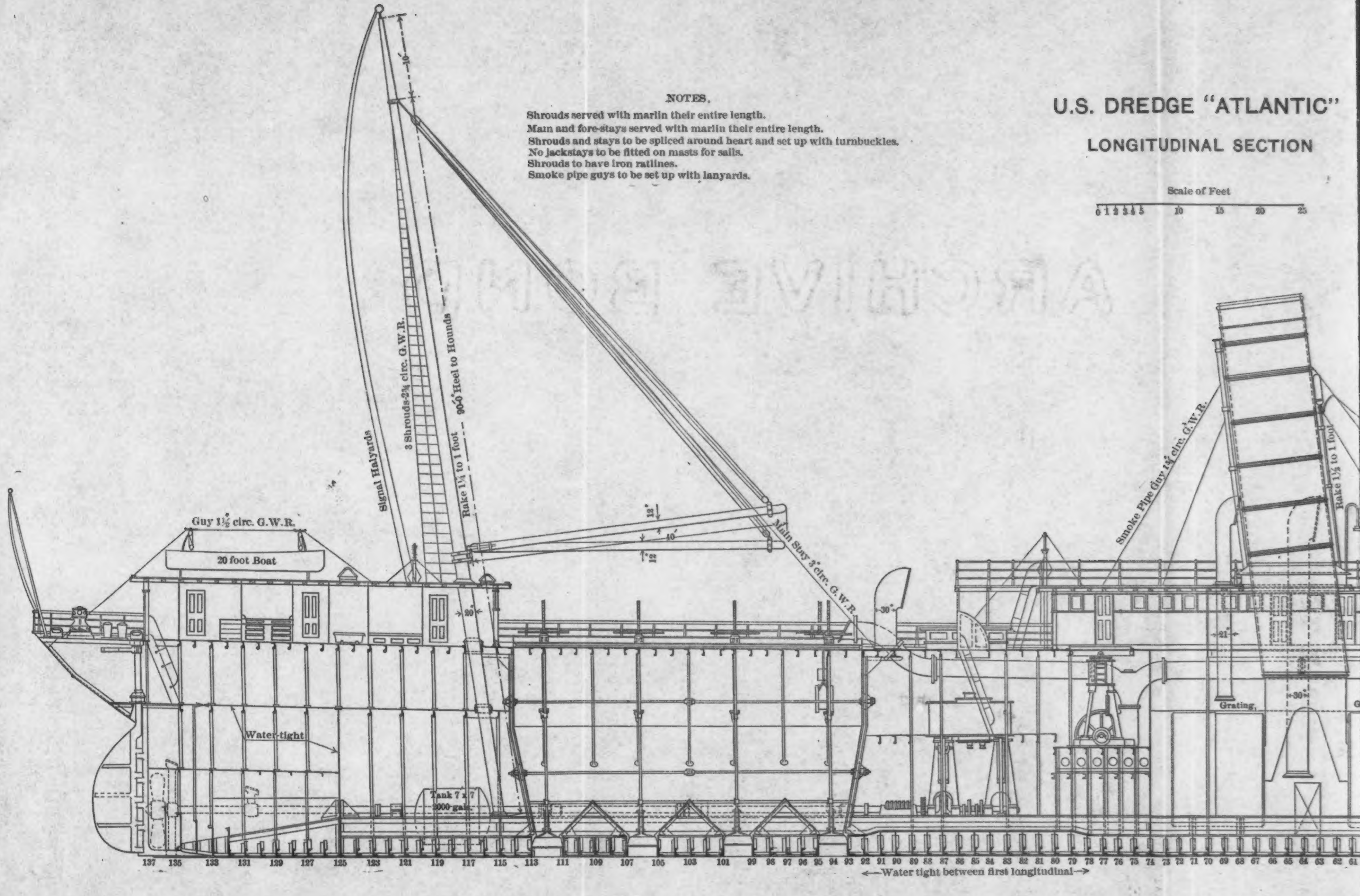
LONGITUDINAL SECTION

Scale of Feet

0 1 2 3 4 5 10 15 20 25

NOTES.

Shrouds served with marlin their entire length.
Main and fore-stays served with marlin their entire length.
Shrouds and stays to be spliced around heart and set up with turnbuckles.
No jackstays to be fitted on masts for sails.
Shrouds to have iron ratlines.
Smoke pipe guys to be set up with lanyards.



NOTES.

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U.S. DREDGE "ATLANTIC"

LONGITUDINAL SECTION

Scale of Feet

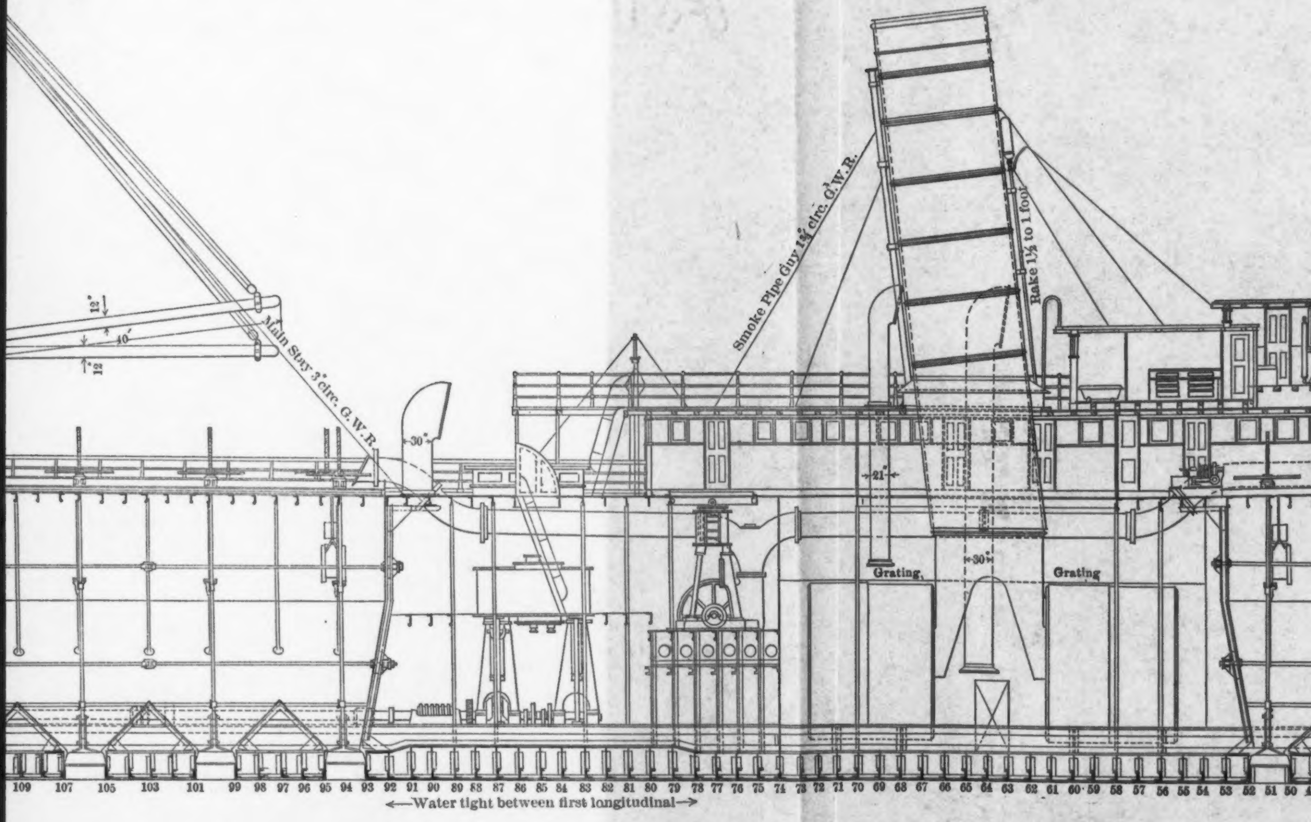
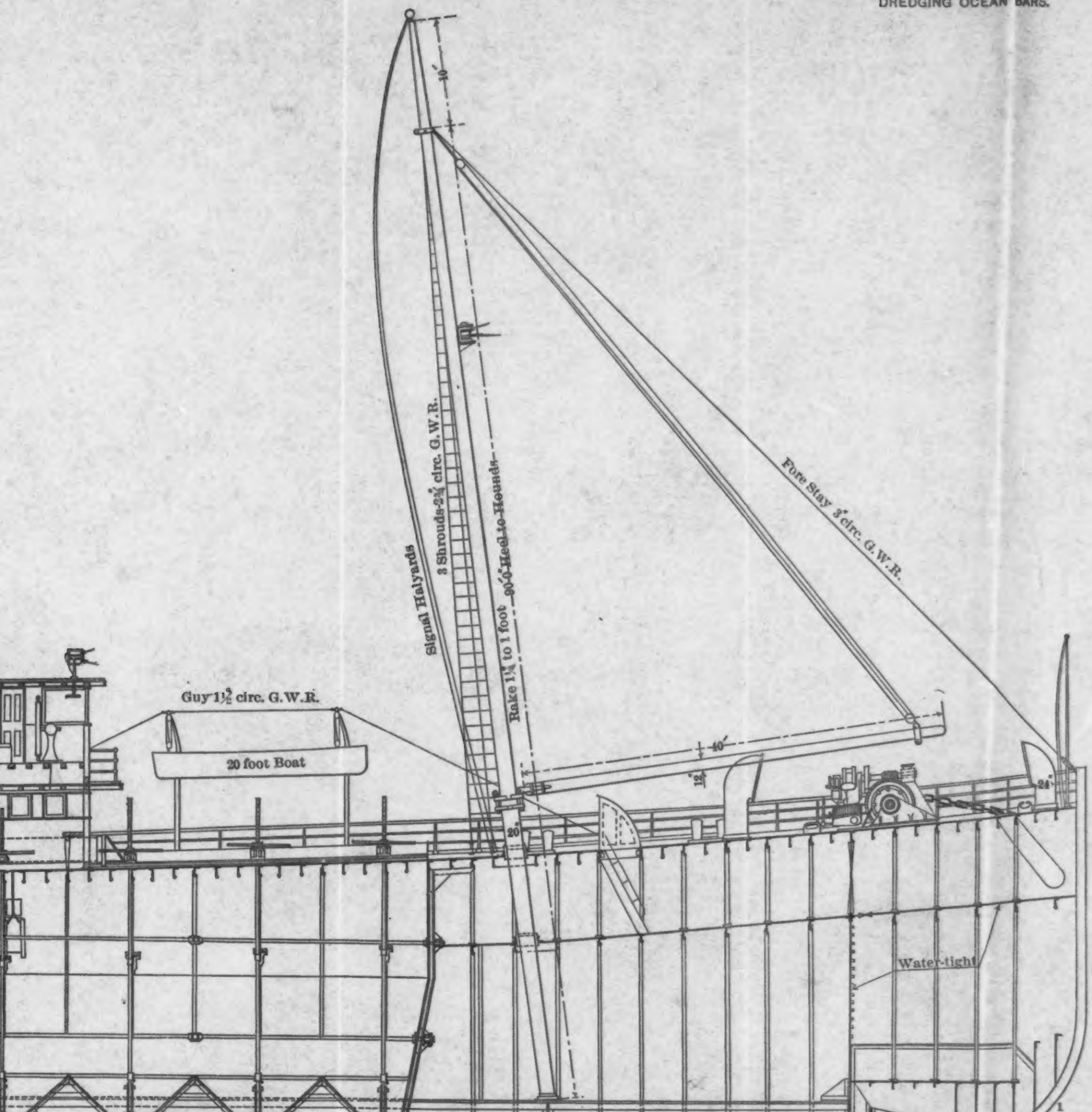


PLATE XXIX. VOL. LIV. PART C.
TRANS. AM. SOC. CIV. ENGRS.
INTER. ENG. CONG., 1904.
SANFORD ON
DREDGING OCEAN BARS.



but the contract price for her construction was only $358 400. Her contract date for completion is August 21st, 1905. As her proposed work will be in shoal water, the quality of seaworthiness is less important than in the case of dredges designed for work on ocean bars, and, to some extent, has been sacrificed to large capacity with light draft. Her maximum bin capacity will be about 3 000 cu. yd. She has bin overflows at three levels to adapt her loaded or partly loaded draft to the varying conditions at different points on the river. Her crew will be quartered above decks in a raised forecastle. Notwithstanding these differences in design, as compared with the design of the *Manhattan* and *Atlantic,* for instance, she will still be much more seaworthy than any of the dredges constructed by the Government prior to 1900, so that she can be used at exposed localities along the coast, if at any time during her life it should become desirable. Table 6 contains data regarding all the sea-going, self-contained dredges constructed since 1900, or now under construction by the Government.

Fig. 2, Plate XXV, and Figs. 1 and 2, Plate XXVII, show three of the foregoing dredges either during construction or after completion. The dredge *Atlantic,* a working model of which was on exhibition in the Government Building, Louisiana Purchase Exhibition, is a type of all these. Its design is illustrated by Plates XXVIII, XXIX and XXX. Each side of the dredge has its independent dredge-pumping outfit, consisting of centrifugal pump, engine, suction and discharge pipes.

The suction pipes, one on either side of the steamer, about midway between bow and stern, extend laterally from the pumps to the outside of the ship, then, turning with an easy bend at right angles, the vertical portion being over the center or horizontal axis, extend, when not in use, along the sides of the dredge, being held up, lowered and raised by suitable blocks and ropes, which are worked by special hoisting engines. These suction pipes, from 60 to 90 ft. long, according to depth, have suitable mouthpieces, termed drags, provided with detachable scrapers, to put on the bed of the channel and facilitate the ingress of material.

To render the suction pipes flexible, so that they will accommodate themselves to the pitching and rolling motion of the steamer, a section of the pipe about 10 ft. in length, located a few feet from the

TABLE 6.

	Sabine.	*Cumberland.*	*Chinook*	*Gen. Abbot.*	*Burton.*	*Gen. Gillespie.*	*Benyaurd.*	*Manhattan.*	*Savannah.*	*Atlantic.*	*Key West.*	*St. John.*	*Caucus.*	Dredge for Delaware River (not yet named).
Year when completed..	1901	1902	1903	1904	1904	1904	1904	....	....	....	....	....	....	....
Length over all, in feet.	145	200	....	200	177	177	271½	288	177	288	141	200	200	315
Length between perpendiculars, in feet.......	137	185	445	185	166	166	260	274	166	274	130	185	185	300
Beam, moulded, in feet.	33½	40	49	40	38	38	47½	47½	38	47½	31	40	40	52
Depth, moulded, in feet.	12.1	22	41½	22	19	19	23	25	19	25	15	23⅛	23⅛	22½
Draft, light, in feet.....	9	12	*16⅝	12⅓	†9 5/12	†9 1/12	†10¼	†10⅓	....	....	....	....	....	....
Draft, loaded, in feet...	....	18	*25⅓	18⅓	....	....	....	....	....	....	....	....	....	....
Bin capacity, in cubic yards (measured to top of coaming)........	334	1 000	3 600	1 000	935	935	1 925	2 125	935	2 125	....	750	750	3 000
Number of propelling engines................	2	1	2	1	2	2	2	2	2	2	1	1	1	2
Size of propelling engines..................	13-26-in. / 22-in.	22-44-in. / 30-in.	22½-36½-60-in. / 48-in.	22-44-in. / 30-in.	15-30-in. / 24-in.	15-30-in. / 24-in.	20-40-in. / 30-in.	22-44-in. / 30-in.	15-30-in. / 24-in.	22-44-in. / 30-in.	17-32-in. / 24-in.	22-44-in. / 30-in.	22-44-in. / 30-in.	22-44-in. / 30-in.
Horse-power of engines.	550 total	850	3 420 total	850	650 total	650 total	1 135 total	1 700 total	650 total	1 700 total	365	850	850	1 700 tota
Number of dredging pump engines.........	2	2	2	2	2	2	2	2	2	2	1	2	2	2
Size of dredging pump engines............	10 by 12-in.	14-26-in. / 18-in.	13-20-33½-in. / 18-in.	14-26-in. / 18-in.	12-22-in. / 14-in.	12-22-in. / 14-in.	16-32-in. / 20-in.	16-32-in. / 18-in.	12-22-in. / 14-in.	16-32-in. / 18-in.	12-22-in. / 14-in.	14-26-in. / 18-in.	14-26-in. / 18-in.	16-32-in. / 18-in.
Horse-power of pumping engines............	100 total	480 total	1 000 total	480 total	340 total	340 total	762 total	762 total	340 total	762 total	170	480 total	480 total	762 total
Number of pumps......	2	2	2	2	2	2	2	2	2	2	1	2	2	2
Size in pumps, in inches.	10	18	20	18	15	15	20	20	15	20	15	18	18	20
Number of boilers......	2	2	4	2	2	2	4	4	2	4	1	2	2	4
Size of boilers, in feet...	10 by 11	14 by 12	{2-17 by 14; 2-10 by 14}	14 by 12	13 by 12	13 by 12	14 by 12	14 by 12	13 by 12	14 by 12	13½ by 12	14 by 12	14 by 12	14 by 12
Type of boilers..........	Scotch	Scotch	Scotch	Scotch	Scotch	Scotch	Scotch	Scotch	Scotch	Scotch	Scotch	Scotch	Scotch	Scotch
Working pressure, in pounds...............	125	125	175	125	125	125	125	125	125	125	125	125	125	125

* Before conversion into a dredge. † Mean draft on trial trip.

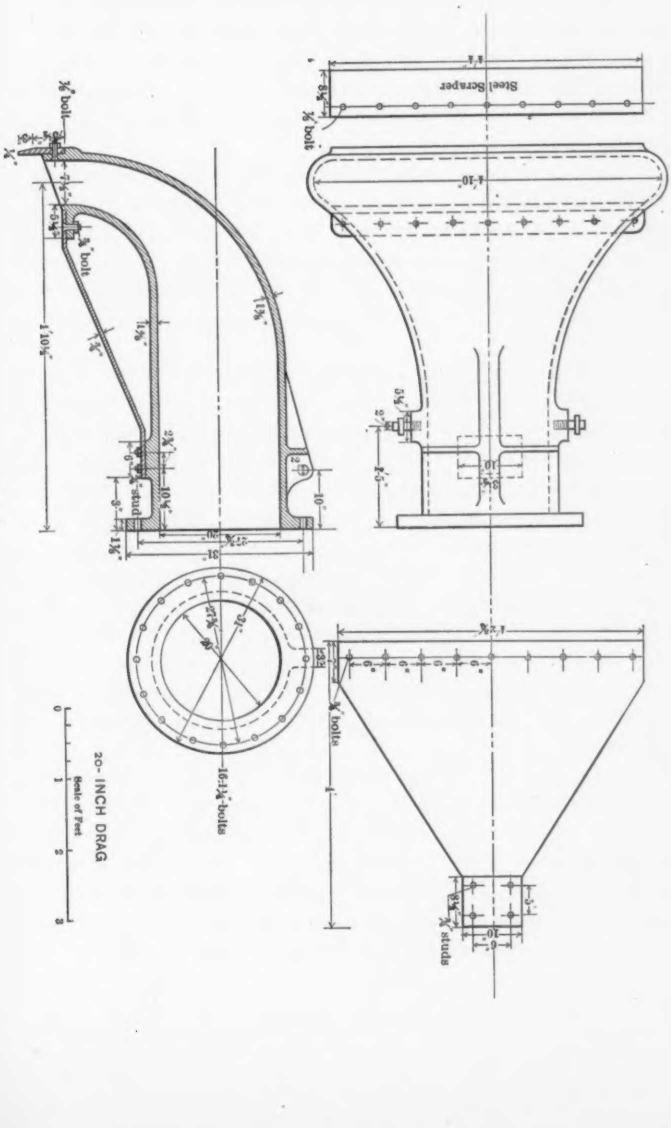


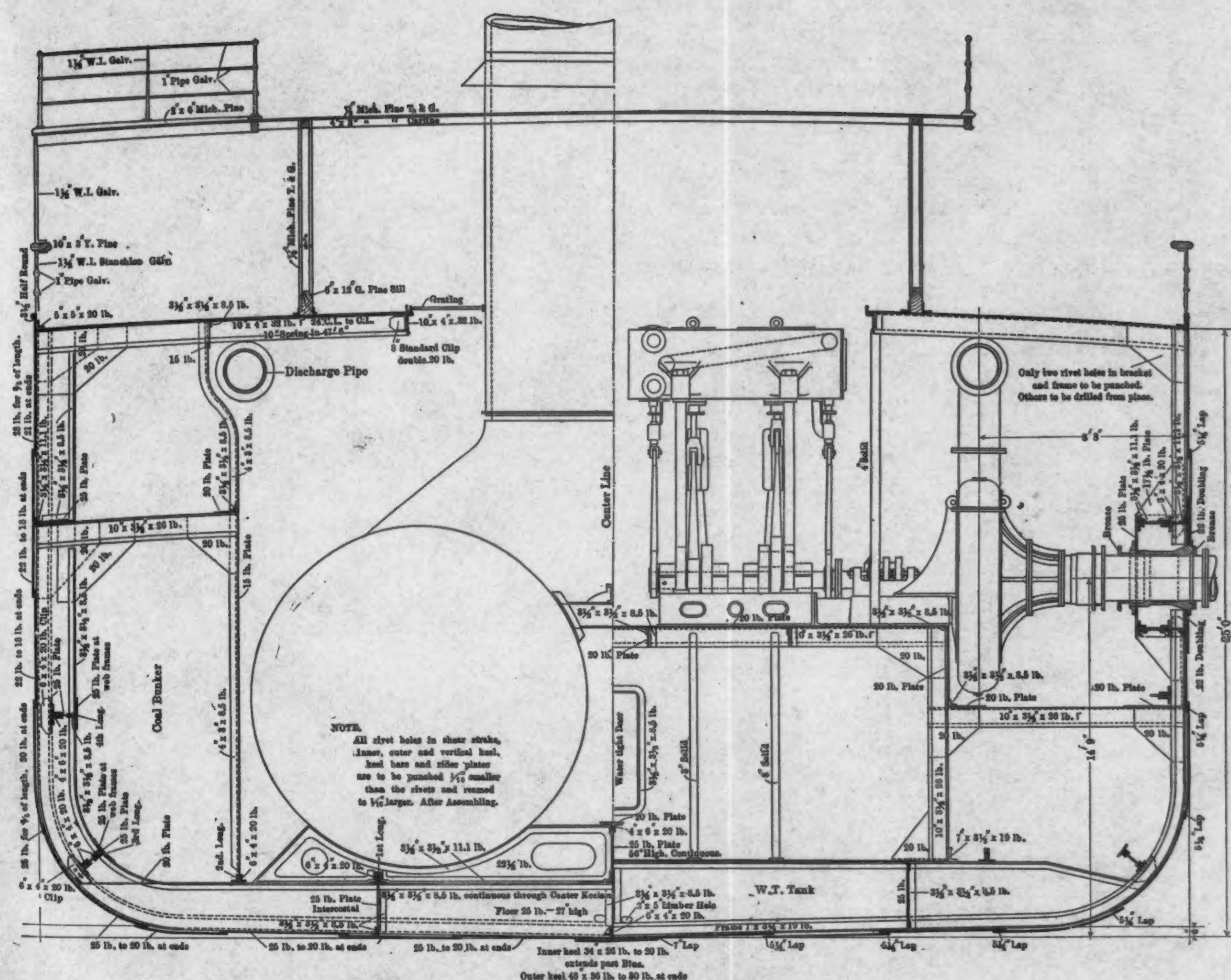
Fig. 6.

elbow, consists partly of rubber. This flexible section is supported by a special arrangement of triple chains and blocks against the vertical strain caused by the weight of the pipes themselves and what passes through them, and by tension chains against the longitudinal strain of the drags resting on the bottom. Each pump discharges its material in both forward and after bin by a Y-pipe with a distributing valve.

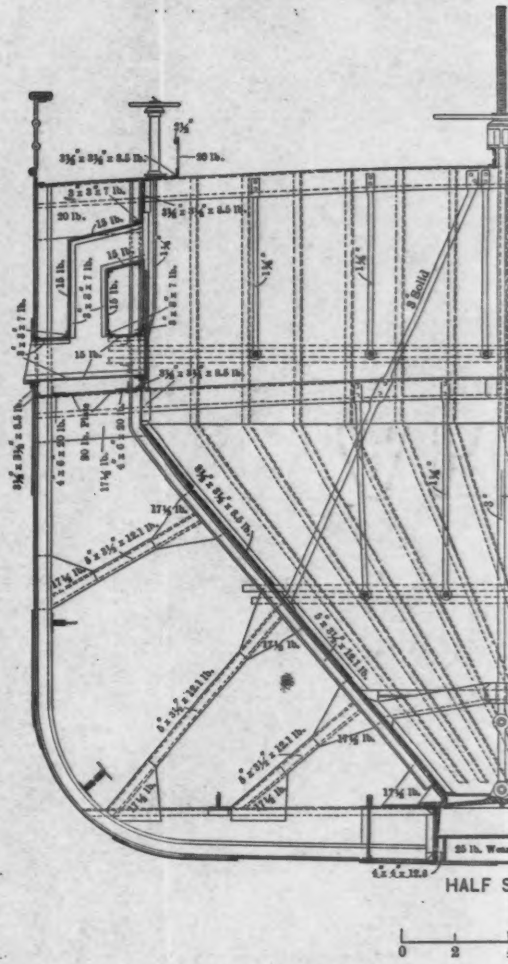
The gates at the bottoms of the bins are of cast steel, and close against cast-steel gate frames. They are opened and closed by a rod, operated at the top by hand-wheels, or by steam, as may be desired. These dredges are operated under just sufficient speed to give them steerage way. Ranges, on which they hold themselves as closely as possible, are indicated by suitable structures on shore or by buoys or piles in the water.

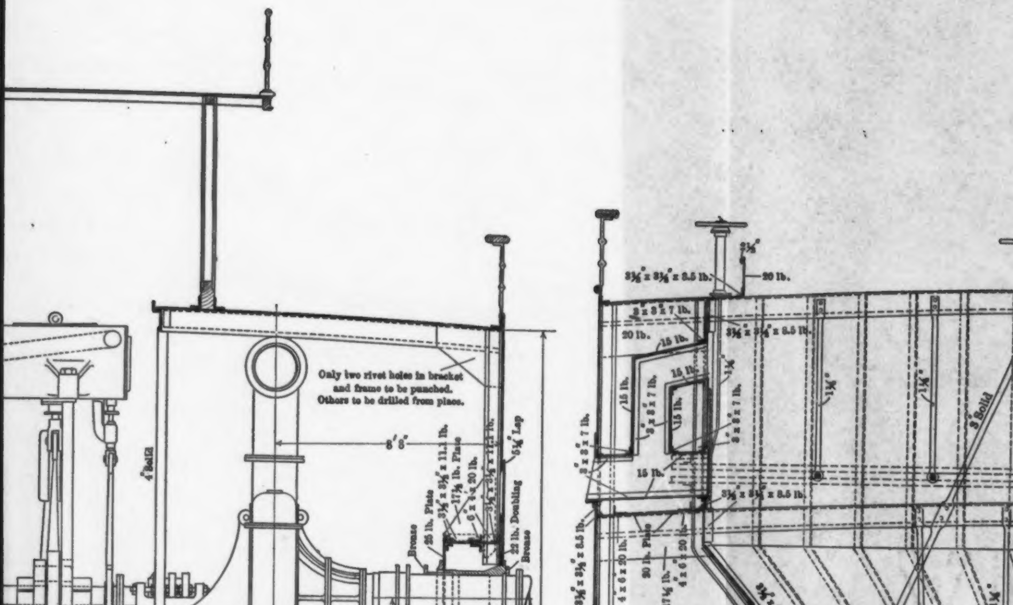
One of the most annoying details in service is the flexible member of the suction pipe. Various forms of ball and slip joints have been tried, with varying but indifferent results. The form of flexible member provided for the *Atlantic* is shown in Plate XXXI. This consists of a specially constructed rubber hose, firmly connected to cast-steel flanged nipples, as shown. The inner tube should be of pure Para rubber, on account of the higher resisting qualities of the pure gum as compared with any rubber compound. In sand-blast hose, for instance, it has been found that for a certain service a hose having a tube composed of 45% pure Para gum will last from 2 to 3 months, while with a tube containing 96% of pure Para gum the hose, for the same service, will last from 10 to 12 months, showing conclusively that the hose composed of pure Para rubber is the better and cheaper.

Another detail, on which much time and thought has been expended, is the drag. Various forms have been tried from time to time, but the two shown by Fig. 6 and Plate XXXII have given the best results thus far. It should be stated, however, that no single design of drag has proved equally efficient in all kinds of material, some forms doing better work in sand, while others have done better work in mud and clay. Quite a variety of forms of scrapers have been used with these drags, being adapted to the different materials in which the work was done.



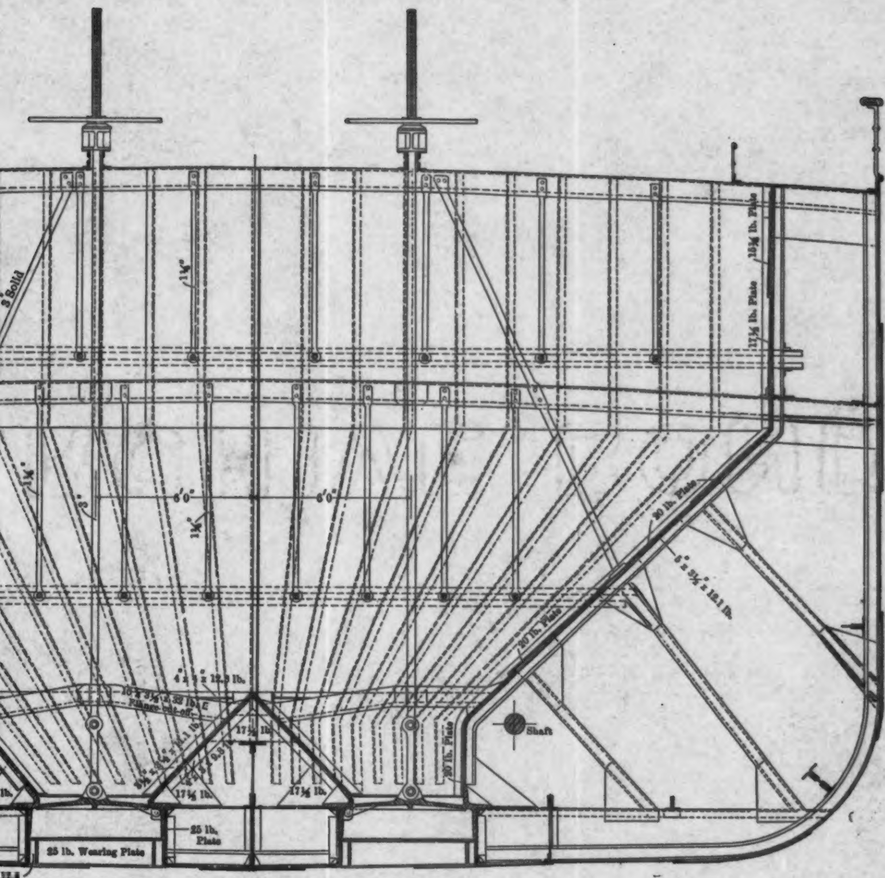
SECTIONS AT FRAMES 73 AND 80
LOOKING FORWARD





Only two rivet holes in bracket
and frame to be punched.
Others to be drilled from place.
8′ 6″
4″ Solid
20 lb. Plate
20 lb.
20 lb. Plate
20 lb. Plate
20 lb. Plate
10″ x 3½″ x 26 lb.
20 lb.
20 lb.
20 lb.
3½″ x 3½″ x 8.5 lb.
Bronze
25 lb. Plate
17½ lb. Plate
22 lb. Doubling
Bronze
22 lb. Doubling
5¼″ Lap
5¼″ Lap
5¼″ Lap
5¼″ Lap
5¼″ Lap
4¼″ Lap
5¼″ Lap
25′ 0″
14′ 9″
2″ Solid
7″ x 3½″ x 19 lb.
W.T. Tank
25 lb.
3½″ x 3½″ x 8.5 lb.
3½″ x 3½″ x 8.5 lb.
20 lb.
15 lb.
15 lb.
15 lb.
3½″
3″ Solid
17½ lb.
17½ lb.
17½ lb.
6″ x 3½″ x 12.1 lb.
20 lb. Plate
4″ x 4″ x 12.8
H
0
2

PLATE XXX. VOL. LIV. PART C.
TRANS. AM. SOC. CIV. ENGRS.
INTER. ENG. CONG., 1904.
SANFORD ON
DREDGING OCEAN BARS.



HALF SECTION OF FORWARD AND AFTER BINS.

Scale of Feet
2 4 6 8 10 12 14 16 18 20

Performance of Dredges.

During the season of 1904, the rapid progress which has been made in the construction of a large number of these dredges, under direction of the writer, as has already been indicated, together with the necessity of directing details of work in a large engineering district, has left little time for the compilation of data regarding the work of dredges now in service.

The following are monthly reports for July, 1904, of the *Gedney,* working at New York Harbor, the *Gen. C. B. Comstock,* working at Galveston, Tex., and the *Sabine,* working on the bar outside the mouth of South Pass, Mississippi River. These may be taken as typical of the work of the older and smaller class of dredges under rather favorable weather conditions.

Dredge *Gedney.*

Location of work, North Side of Gedney Channel, New York Harbor.	
Depth of water (survey of January, 1904)	27 to 30 ft. M. L. W.
Depth required	30 " M. L. W.
Range of tide	4.6 "
Material dredged	Sand and gravel in varying proportions,
Cubic yards removed	53 193
Loads	88
Yards carried per load, average	604
" dredged per minute, average	15.0
Time dredging	59 hr. 14 min.
" turning	2 " 37 "
" running to dumping ground	53 " 48 "
Average speed, loaded	5.4 knots.
Time running from dump to working ground	32 hr. 11 min.
" " " " " anchorage	18 " 24 "
" " " " " wharf	18 " 02 "
" " " anchorage to working ground	12 " 59 "
" " " wharf to " "	12 " 29 "
" " " anchorage to anchorage	1 " 12 "
" lost repairing (while under steam)	1 " 06 "
" lost from other causes (while under steam)	05 "
" dumping	11 " 45 "

Average time dumping per load................ 8 min.
Total time under steam........................223 " 47 "
Average speed, light..........................6.9 knots.
" " " (to and from wharf)........7.4 "
Approx. " while dredging..................1.5 "
Time lost due to fog..........................$1\frac{1}{4}$ days.
" " " " rough sea..................... $\frac{1}{2}$ "
" " " " repairs....................... $\frac{3}{4}$ "
" " " " coaling ship...................$2\frac{1}{2}$ "
" " " " other causes.................. $\frac{1}{2}$ "
" actually working........................$19\frac{1}{2}$ "
Distance from working grounds to dumping grounds, mean..........................3.3 nautical miles.
Coal burned (pea coal)........................207 long tons.
Water used....................................35 300 gal.
Average cost of dredging per cubic yard (based on actual cost of coal, water, rent of wharf, wages of crew, and mess bills, and on average of ten years' cost, per working day, of repairs and supplies)....................5.9 cents.

Dredge *Gen. C. B. Comstock.*

Quantity of material dredged....................67 476.2 cu. yd.
Character of material dredged.................Sand, mud and clay.
Distribution of working time :

Anchorage to cut........................	9 hr.	55 min.
Pumping..............................	147 "	29 "
Cut to dump...........................	33 "	35 "
Dumping	8 "	10 "
Dump to cut...........................	25 "	27 "
Dump to anchorage.....................	10 "	10 "
Time lost turning......................	0 "	00 "
Total hours worked...........	234 hr.	46 min.
Time lost on account of bad weather, Sundays and holidays, washing out boilers and repairs................	220 "	37 "

Cost of operating for the month..........................$2 888.38
Cost of extraordinary repairs for the month................ 773.90
Fuel consumed, 845 bbl. fuel oil at 70 and 75 cents per bbl.

PLATE XXXI. VOL. LIV. PART C.
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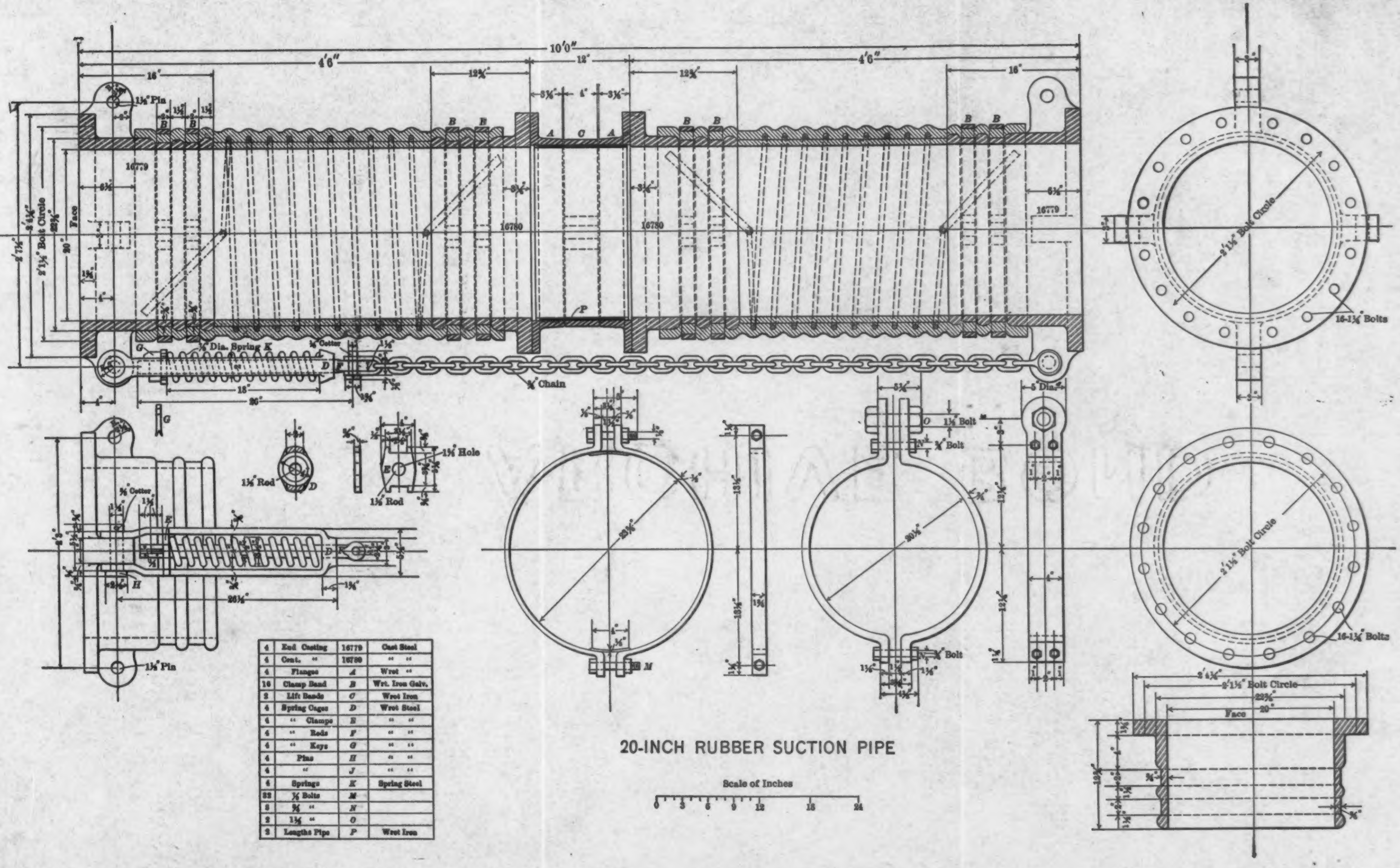
INTER. ENG. CONG., 1904.
SANFORD ON
DREDGING OCEAN BARS.



20-INCH RUBBER SUCTION PIPE

4	End Casting	16779	Cast Steel
4	Cent. "	16780	" "
4	Flanges	A	Wrot "
16	Clamp Band	B	Wrt. Iron Galv.
2	Lift Bands	C	Wrot Iron
4	Spring Cages	D	Wrot Steel
4	" Clamps	E	" "
4	" Rods	F	" "
4	" Keys	G	" "
4	Pins	H	" "
4	"	J	" "
4	Springs	K	Spring Steel
32	⅞ Bolts	M	
8	⅝ "	N	
2	1⅛ "	O	
2	Lengths Pipe	P	Wrot Iron

Scale of Inches

Dredge *Sabine*.

The dredge *Sabine* was transferred on July 13th, 1904, for work beyond the ends of the jetties at South Pass. The dredge left New Orleans on July 14th, arrived at Port Eads on July 15th, and began work beyond the ends of the jetties on the same day. The material removed consists principally of a stiff clay or mud, with some sand. Between July 15th and 30th, the dredge worked $161\frac{5}{12}$ hours, distributed as follows:

Moving to and from dredging position	$13\frac{1}{12}$	hr.
Pumping	102	"
Dumping	28	"
Repairs	$12\frac{4}{12}$	"
Taking aboard fuel	6	"

During this time the dredge removed 286 loads of material containing a total of about 55 770 cu. yd. of solid matter. The expenses of the dredge from July 13th to 31st, were about $1 250, making the average cost per cubic yard of material removed about 2¼ cents. From the 13th to 31st, 439 bbl. of fuel oil were consumed, of which 401 bbl. were used in connection with the dredging operations proper.*

Summary of Progress Made.

A demonstration of the practicability of dredging on exposed bars in nearly all kinds of weather, and the marked diminution in cost of dredging on such bars, with consequent modification of views as to the most practical method of deepening and maintaining channels over them, has already been mentioned. The necessity has been produced of constructing dredges capable of removing vast quantities of material within a reasonable time and at a minimum cost. The most notable advance in construction which has been made, therefore, is a very marked increase in the average size of these dredges. This is shown clearly by a comparison of the tables giving the dimensions and capacities of those constructed prior to 1900, and those constructed and planned since that date.

In many of the earlier dredges most of the machinery was

* In August, 1904, this dredge removed 67 860 cu. yd. at this locality, the average cost for working expenses being 3 cents per cu. yd.

placed near the stern, the result of this being to give excessive light draft. The arrangement has been discarded in all the new dredges. The machinery is now placed amidships, and bins located forward and aft of it.

Experience having shown the advantage of using two suction pipes instead of one, two are provided on all the newer dredges for which the size will permit.

The use of overflows at two different levels has already been mentioned.

During the past few years the Department has frequently found it necessary to send these dredges to points for which they were not designed, in order to give immediate relief to channels which had closed, or in which shoals had formed. This has suggested the desirability of designing dredges so that, while suited to the locality for which they were built, they may also be used, if necessary, under quite a variety of conditions.

All the newer dredges are made more seaworthy than the older ones, the idea that the protection afforded by jetties for dredging on ocean bars was of great value having been discarded. In conclusion, it may be said that all these dredges have been built under limits of cost which were either fixed or nearly so. In endeavoring to obtain the most efficient machine within the limit of cost, it was realized that, in subsequent operations, alterations could be made to such portions of the construction as would readily admit of it. Special attention, therefore, was directed to planning the practically unalterable portions, notably the hull and propelling machinery, so as to give these the utmost possible efficiency compatible with cost limit. Many of these dredges have not yet been provided with all the auxiliaries which will probably be found desirable in the future. It is expected also that experience will indicate the desirability of making numerous minor improvements to the dredges as constructed. The fact that so many of them have been planned at practically the same time has made it impossible in planning each to utilize the experience obtained during the service of its predecessor; nevertheless, it is believed that the work of 1905 will demonstrate that, in a very large measure at least, they will accomplish the results, in cost and amount of work, for which they were built.

PLATE XXXII. VOL. LIV. PART C.
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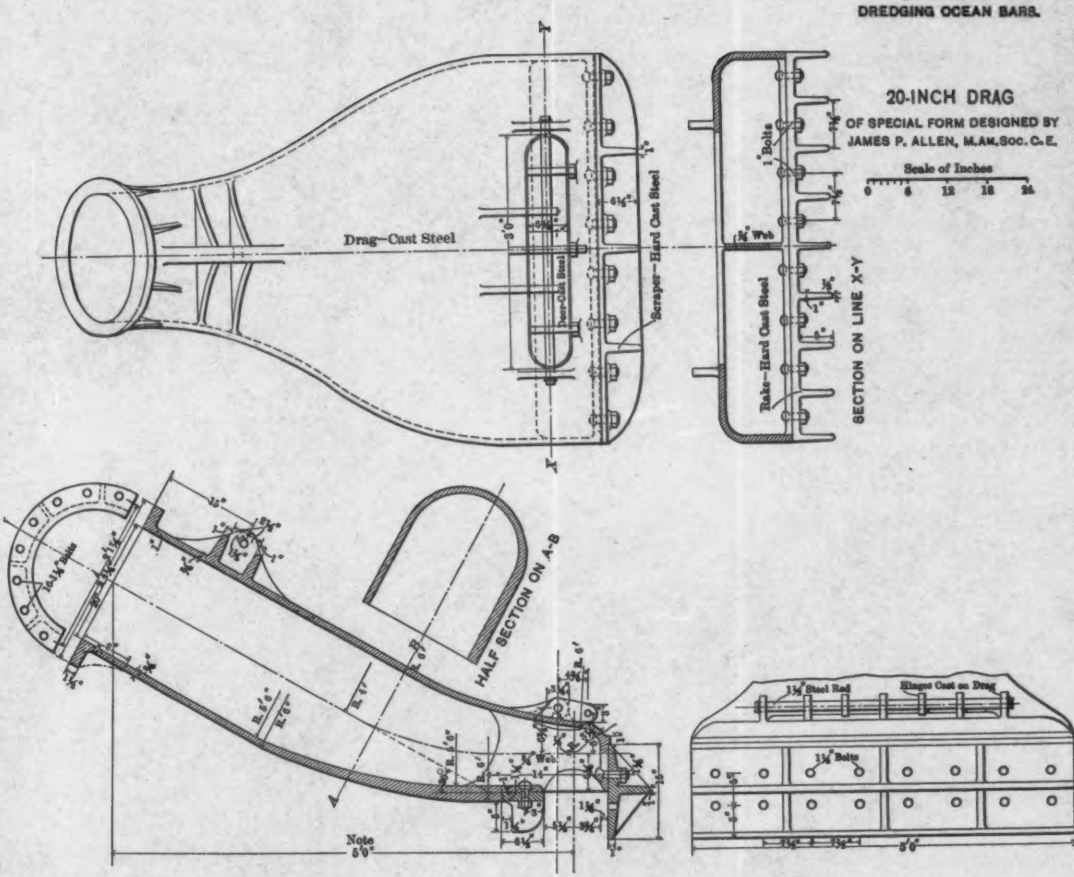
INTER. ENG. CONG., 1904.
SANFORD ON
DREDGING OCEAN BARS.



TRANSACTIONS

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

Paper No. 40.

DREDGES: THEIR CONSTRUCTION AND PERFORMANCE.

REVIEW OF GENERAL PRACTICE.

By Jean Hersent.*

Translated from the French
By Paul A. Seurot, M. Am. Soc. C. E.

Public improvements in all parts of the world are becoming more and more important every day, and have given a new impulse to the researches of engineers, manufacturers, and contractors, whose combined efforts have resulted in the construction of powerful machinery giving greater output with less cost.

The increase of production, however, has not been quite proportional to the increase of power of the machinery; in fact, a dredge having a mean capacity of 300 h. p. has an output only double that of a 100-h-p. dredge, and, beyond a certain power, the effective output is further decreased.

The output of a dredge depends upon different factors, the influence of which is very variable, and which the writer will try to analyze.

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For a bucket dredge these factors are: The capacity and the shape of the bucket, which must be suitable for the nature of the ground; the mode of power transmission between the engine and the dredging apparatus; the size of the dredge and the type or shape, which must be adapted to the conditions under which the work must be executed.

For suction dredges: The diameter of the suction pipes and the style of pumps.

The dimensions and the power of the apparatus, as a whole, are so many elements, each having its influence upon the production, according to the nature of the ground, and the location and importance of the rivers or estuaries where the work must be executed.

The bucket is the principal part of the dredging apparatus; its capacity has, of course, a great influence upon the production. The capacity generally adopted for the buckets of a dredge of average power is from 300 to 400 liters; beyond these figures the loading and unloading of the buckets are less regular. It is possible, however, to use large buckets, ranging in capacity from 800 to 1 000 and even 1 500 liters, in material which is easily excavated.

The shape of the bucket has also a very important influence upon the output; for instance, it may be especially arranged for digging when the ground is resistant, or for rapid unloading of materials when the ground is soft, flowing, and easy to dredge.

When the dredging has to be done in clays, marls, hardpan, or rock formation, it is desirable to get a bucket having a more compact shape, and with the cutting edge as nearly as possible normal to the surface of the ground, so as to attack the soil more efficaciously, and to increase the power of the bucket. These conditions, however, vary, because it is necessary to consider the adhesion of thick and sticky materials, which, to facilitate the unloading, sometimes require a bucket of intermediate shape.

In practice, the output is regulated by the speed of the bucket-chain, that is, by the number of buckets attacking the ground in one minute. If the ground is easily dredged, it is estimated that this number is 15 to 18; in grounds more resistant or thick and sticky, it is from 12 to 14, and, in still more resisting grounds, the speed is reduced to 10 buckets per minute; and even then the hard ground must be fissured, or must have been previously broken up, because,

in attacking solid, unbroken, compact grounds, the machinery would become disabled. The nature of the ground to be dredged is the most important factor of the output and, consequently, of the cost. It seems, then, interesting to classify the different kinds of grounds according to the ease or difficulty with which they are dredged. The material most easily dredged is gravel when the pebbles measure from 2 to 5 cm. in diameter; then follow in order, mud, muddy sands, sand, clay and marls, hardpan and rock formation.

The mode of transmitting the power to the dredging machinery is another important factor in the output of the apparatus. If this is done directly by straight gearing, the maximum effort of the machine is transmitted to the bucket-ladder; if it is done by belts or an endless chain, there is still a very good output, although somewhat less than in the first instance. If, on the other hand, the transmission is by bevel-gearing, there is a loss of power of from 20 to 25% due to friction.

In the case of suction dredges, the nature of the sand and the type of pump have also a great influence upon the output. A pump more or less appropriate corresponds to each grade of sand (according to fineness and weight). With very fine sand, it is advantageous to use a pump with 3 or 4 blades, whereas, with coarser or heavier sand, 2 blades are sufficient. These are results of experiments which are always worth knowing, but which must be ascertained in every case. If the sand is too fine, it is easily pumped, but is very difficult to unload into the tanks or hoppers. In every case, the good choice of the apparatus and its appropriateness to the kind of work required, are essential to economical results.

According as ordinary bucket dredges, ladder bucket dredges, marine or suction dredges of different types are used, the output will vary from 100 to 600 cu. m. per hour, even attaining 2 000 cu. m. in very favorable materials and with powerful machines; while, on the other hand, in rocky bottoms the output will fall to 20 or even 10 cu. m. per hour. The difference in the cost of the work is easily seen by these figures. Modern dredges, the power of which has been materially increased, have permitted the cost of work to be lowered, but not always proportionately to the increase of power of the machinery and of its capacity.

The cost of actual dredges is much higher than it was 15 or 20

years ago. Machines which at that time cost 25 000 to 50 000 francs were raised to 200 000, then to 500 000 francs, and some gigantic dredges have even been built at a cost of 1 000 000 and 1 500 000 francs (Bates dredges, built for Russia, bucket dredges having a capacity of 1 500 liters, in the Lobnitz shops, and the dredge *Thomas* built for the New York harbor improvements). The interest on the invested capital, the coefficient of amortization of plant, the cost of transportation of the machinery, and the insurance, are all elements to be considered in figuring the cost of the work. To these must be added cost of maintenance, repairs, shops, accessories, special machinery, and all that is necessary to insure the good working and operating of dredges. According as the work is located in a new and sometimes unhealthy country, or in a section having a healthy and good climate, the cost of dredging may be doubled or more than doubled. The output also varies according to theoretical or practical considerations.

Considering the cost of dredging from a practical viewpoint: in manufacturing centers where labor is plentiful, the cost with bucket dredges may be calculated at from 0.50 franc to 1.25 francs per cu. m. for muddy sands, mud, and soft and non-sticky materials. These unit prices increase, with the consistency of the material, to 5 and 10 francs per cu. m. for sticky materials or more or less rocky conglomerates. But the ground to be dredged must always be broken up when it is a rock formation or even a compact marl.

For suction dredges, the cost must not be calculated at less than 0.45 franc per cu. m. Some lower figures have been mentioned, but may be considered as theoretical, because, to reach the limit just given, the conditions must be exceptional. To get below this price, all conditions permitting the reduction of the cost must be present: dredging of several millions of cubic meters, light movable materials, powerful machinery, good climate, cheap and plentiful labor, etc.

Upon the whole, it may be said that the improvements made during the last ten years have been very great, as is shown by scrutinizing the principal characteristics of the latest dredges. These improvements are all the more important because they are not confined to one class of apparatus built in a particular country, but are the sum of all improvements made by contractors and manufacturers in the whole world, in Europe as well as in America.

The tendency is to build more and more powerful dredges; but, while these machines apparently have important advantages, they are not the most economical. If dredging in recent alluvia has to be done on a very large scale, as in the Mississippi improvements, at Paraná, in New York Bay, or at Buenos Ayres, where the yardage amounts to tens of millions, it is evident that powerful machinery has a distinct advantage. However, this increase must not be exaggerated, because, in case of accident or breakdown of any part of the machinery, there is immediately an immobilization of very important capital, and a stoppage of work. It is, then, wise always to proportion the power and the number of working units to the magnitude of the work to insure regularity and continuity of action; and the dredge of average power, say of 300 to 600 h. p., is generally more advantageous, even for very great works, and even though it be necessary to increase the number of dredges to obtain an equivalent output.

The dredge of great power, built especially for a certain kind of duty, cannot readily adapt itself to all sorts of ground, may become less economical in certain conditions, and runs the risk of being idle more than any other. If, on the contrary, dredging is to be done in hard materials or rock formations, the dredge of average power, say 250 to 300 h. p., with buckets of 400 liters capacity, becomes the most practical, and may be used in every case.

As to suction dredges, it is well to make them as powerful and with as large capacity as possible, but, however, in proportion to the conditions of navigation in the vicinity of the section where they must be used.

If it is intended to improve or deepen a river, the capacity must not be greater than 600 to 1 000 cu. m., depending upon the draft that may be used; but, in the case of dredging or maintaining an estuary, and when the dredged materials have to be carried to sea, the capacity may reach 2 000 cu. m. or more. In the last case, hopper bucket dredges of a capacity varying from 600 to 1 000 cu. m. can be used, but only for work to be done at sea and when the materials cannot be raised by pumping.

In conclusion, it may be said that, from the point of view of construction, the improvement of dredging machinery has consisted chiefly in the increase of power of the machines used, in an increase

TABLE 7.—SPECIFICATION OF THE PRINCIPAL

Date of Construction.	Names.	Name of Builder.	Kind of Dredge.	Dimensions.		
				Length.	Width.	Depth at Draft Line.
1893..	*Pas-de-Calais*	Sâtre & Co. (French).	Hopper bucket	54.80	10.10	4.25
1894..	*Guisendam*		Bucket	32.00	5.80	2.60
	Elisabeth		do	40.50	6.50	3.15
	Schelde I	Smit	Suction	35.00	6.80	3.40
	Schelde II.		do	56.40	8.60	3.90
	Schelde III.		Bucket	45.00	7.00	3.35
1895..	*Gelderland*	Smit & Sons. (Holland)	Suction	68.00	10.50	4.50
	Thomas		do	91.50	16.00	7.60
	Hephæstos		Bucket marine	45.00	8.50	2.50
	Bayonne		Hopper suction	53.50	8.90	3.80
	Andrée		Bucket	55.50	10.25	4.00
1898..	*Volga*	Cockerill Co.	Suction and discharging..	65.00	9.50	2.75
	Delta	World Building Co. (U. S.)	do	53.30	11.60	2.50
1901..	*Montevideo*	Smulders. (Holland).	Bucket and suction	75.00	12.50	5.25
	Quo Vadis		Suction	47.00	9.00	3.90
	Adm. Gironde		Bucket	40.00	8.75	3.40
1902..	*Adon. Tunis*		Marine - hopper - bucket - discharging	40.00	7.75	3.65
	Béta	Mr. Bates. (U. S.)	Suction and discharging..	52.40	12.20	2.20
1903..	*Samson*	Messrs. Armstrong-Whitworth	Suction	79.30	15.85	2.45
	Hercule	do	do	79.30	15.85	2.45
	Rosario D. I.	Smulders. (Holland).	Bucket and discharging	47.50	9.30	4.00
	Rosario D. II. and D. III.	Smit & Zoon. (Holland)	Hopper suction discharging	60.00	9.00	4.00
	Dredges Nos. 5, 6, 7, 8, 9, 10 and 11	Hersent	Bucket	30 to 35m	6 to 7m	3.00

DREDGING MACHINES BUILT BETWEEN 1894 AND 1903.

Capacity.		Output.		Power.	Speed.	Discharge.		Destination.	Remarks.
Buckets.	Wells.	Bucket Dredge.	Suction Dredge.			Height.	Distance.		
*	......	300	......	610	6.25	......	......	Boulogne-sur-Mer.	*Removable buckets of 300 to 500 liters.
350	......	160	......	130	......	......	......	Escaut (Scheld)	
450	......	225	......	180	......	......	......	do	
......	......	......	400 (a)	400	......	......	......	do	Empties the barges placed alongside. (a) According as the sand contains more or less clay the output is from 400 to 500 cu. m.
......	600	......	1 200	300	......	......	......	do	Forces the dredged materials from its compartments (wells).
600	......	300	......	300	......	......	......	do	
......	850	......	1 260	700	9	4.00	300	Portugal.	
......	......	......	......	......	......	......	......	New York Harbor.	Suction pipe measures 1.37 m. in diameter.
500	......	300	......	......	......	......	......	German Harbor, Tsington, China.	
......	......	......	425	450	8	......	......	Adour.	
750	......	350	......	500	7.5	......	......	Havre.	
......	......	......	†	5 500	......	......	......	Russia.	†The output is: 3 000 cu. m. maximum. 1 500 " " minimum.
......	......	......	600	......	......	......	......	Mississippi.	
800	800	500	1 200	1 000	8.2	......	......	Montevideo.	
......	450	......	960	300					
600	......	300	......	300	......	......	......	Gironde.	
200	250	50 to 120	120	180	5	2.00	300	Tunis.	
......	......	......	1 150	375	......	......	304	Mississippi.	During trials the output was 3 745 cu. m.
......	......	......	1 100	1 100	10	9.00	1 800	Queensland.	
......	......	......	600	600	10	......	......	do	
650	......	585	......	700	10	......	500	Rosario.	
......	500	......	1 200	600	10	......	......	do	
350 to 500	......	150 to 250	......	100 to 200	....	......	......	French Colonies and Foreign Countries.	

of the strength of the machinery in bucket dredges, and in an increase in the dimensions of hoppers and compartments in suction dredges.

As to the output, it is found best to use bucket dredges of average size, because it is then possible to operate them at all times and everywhere with a regular and continuous output, whereas, when suction dredges are used for removing exceptional volumes of materials, it is preferable to use those having great capacity.

Therefore, to obtain the best results and maximum output, the desideratum is: not to go beyond certain dimensions in bucket dredges; and to proportion the capacity of the dredging machinery to the work to be performed.

TRANSACTIONS

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Paper No. 41.

DREDGES: THEIR CONSTRUCTION AND PERFORMANCE.

CRANE AND LADDER DREDGES.

By T. Kobayashi.*

Generally speaking, there are four kinds of dredges; crane, shovel, ladder and pump dredges. The first two are intermittent in their work and limited in their capacity, while the others are of greater dredging capacity and able to work continuously. In the Osaka Harbour Works all kinds of dredges, except shovel dredges, are now being used. There are:

5 Priestman's "B" type dredges,
2 200-ton non-propelling ladder dredges,
2 600-ton self-propelling ladder hopper dredges,
2 500-ton non-propelling and shore-delivery pump dredges,
2 500-ton self-propelling, pump system, hopper dredges,
5 tugboats, each of 33 tons,
32 100-ton bottom-hopper barges.

Now, as it is very difficult to treat of all the dredging plant within the general limit of 10 000 words, the writer takes crane and ladder dredges as the subject of this paper.

* Engineer in charge of dredging in the Osaka Harbour Works, Japan.

Crane Dredges.

These dredges are commonly known by the names of the makers, as Priestman's, Stothert and Pitt's, Morris and Cuming's, Fouracre's, Bruce and Batho's, etc. Sometimes they are named from the form of bucket used, as grab, clam-shell or digger dredges. Whatever the name may be, the essential part of the dredge is the bucket, which may be raised or lowered by a crane. Being connected with a chain or chains, the bucket raises the material vertically, and can work in any depth, and in spite of wave action.

As this type requires a small staff and occupies a very small space, it is exceedingly useful for working in wells, docks, or other confined spaces, and also for dredging a detached bar which extends over a comparatively small area. Moreover, it lifts material with a smaller percentage of water than any other. The efficiency of the bucket to penetrate the material does not depend upon the force with which it falls, the jaws being framed so as to draw down and penetrate as soon as an upward strain is put on the lifting chain, when the resistance of the soil is not great. But if the resistance is great, the bucket is liable to slip along the surface, instead of penetrating, therefore it cannot be used in hard soils. Moreover, it is not suited for regular plain cutting, as it is designed to dig a number of consecutive holes, and its action is discontinuous.

Bucket.

Chief Points in Bucket Construction.—The following are the chief points to be noted in bucket construction:

1.—It should penetrate the ground easily, without slipping and tumbling.

2.—It should cause itself, when being closed, to be full of earth.

3.—It should open and close automatically.

4.—It should close readily and tightly, permitting no leakage.

5.—No earth should be washed over or drop out when being raised through water.

6.—It should readily discharge its contents, and not require clearing.

7.—It should be simple in construction, have as few wearing parts as possible, and be easily repaired.

Almost every kind of work and earth requires a specially shaped bucket, the suitability of which causes success or failure.

Capacity of Bucket.—As to the relative merits of bucket capacities, opinions have been somewhat divided; however, in a large dredge the weight of the bucket is less in proportion to the quantity of material raised than in a smaller dredge, as may be seen from the following table of Messrs. Wilson and Co.'s grabs:

Capacity of grabs.........	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{3}{4}$	1	cu. yd.
Approximate weight.......	17	22	28	35	cwt.

Thus the weight will have the following relation:

$$W = 13 + 14\ V + 8\ V^2$$

where W = weight, in hundredweights, and
V = capacity, in cubic yards.

Therefore, the bucket of $\frac{1}{4}$ cu. yd. capacity has a dead-weight 1.95 times that of the bucket of 1 cu. yd. capacity, in proportion to the material to be contained. Mr. John Newman said that in a very large bucket the weight may be as little as 0.75 of that of the earth lifted, while in a small bucket it may vary from 1.2 to 1.7 times the weight of the earth, so, in proportion, much more dead-weight has to be raised each time. But it must be kept in mind that the increase in weight, as will be seen later, is necessary for increasing the penetrating power of a bucket.

Form of Bucket.—Some of the old primitive buckets have a single spade, as in the Ives' dredge, or eight spades forming a flat table or tray, as in the Milroy's dredge. At present, the bucket has, commonly, two scoops, which close in a semi-cylindrical form. This form, however, is not fitted for sinking cylinders, because of the so-called "nestling" at the bottom, that is, the material cannot be cleared away from the sides of the cylinders. A modification of this form is a semi-octagonal prism, as in the Stothert and Pitt's or Grafton and Co.'s buckets, which is suitable for a bucket or grab on account of its easy construction. Another kind of bucket having many leaves forms a hemispherical shape when closed, as the Priestman's special bucket, 2 leaves; Bruce and Batho's and Grafton & Co.'s, 3 or 4 leaves; the Knight's patent, 6 leaves, etc. This shape is more suitable for cylinder sinking than the others. Being circular in plan, it can be made of nearly the same size as the internal

diameter of the cylinder, and will cut out the material close to the edge of the curb, and avoid the necessity of what is called undercutting.

Now, in order to lessen the quantity of earth washed away while raising a bucket through water, the bucket must have a minimum surface exposed to the water. Comparing the spherical bucket with the semi-cylindrical bucket, having a square plan, as is usual, and an equal volume, the ratio of contact surfaces will be 1 : 1.2. In this respect the former will be better than the latter; but, having a greater number of leaves, it will be more liable to leak. Mr. H. J. Coles, who used a semi-cylindrical bucket for clearing out a well, 300 ft. deep, found that the amount of material brought up through 150 ft. of water was not perceptibly different from that brought up through 5 ft. of water. Much more, therefore, need not be said as to the bucket's holding spoil in passing through water.

The cutting edge of the bucket, when opened, should be so directed that the tangent plane at that edge will be vertical. Moreover, the bucket, in order to discharge the dredged material easily, has an oval form.

Type of Bucket.—Among the many types of semi-cylindrical buckets, each specially adapted to dredge a particular kind of soil, are the following:

1.—The plain plate bucket, for lifting soft mud, dry sand, grains, etc.;

2.—The plain plate bucket without side tines, having more digging power than the plain bucket, and closing more tightly than a half-tine grab, and so retaining wet material better;

3.—The corrugated plate bucket, a very strong light grab bucket;

4.—The half-tine grab, suitable for excavating hard sand, earth, gravel, coal, or any other material that requires a considerable amount of digging power, this being the form of grab which has the widest range of utility for general work;

5.—The whole-tine grab, used for hard clay, sand, blasted rock and boulder, for clearing weedy growth from canals and rivers, and for other purposes where the maximum digging power is necessary. For some kinds of work the end tines are entirely removed.

Mouthpiece or Cutting Edge and Tine.—As the force with which a bucket can be dropped into the soil is simply that of its own

weight falling a certain distance, special provision should be made for extra strength in the bucket edges. The mouthpiece of a plate bucket is, therefore, of a special steel, about 12 by $\frac{5}{16}$ in. This piece, not being pointed, serves only to strengthen the edge, and not to increase the penetrating power, for which it would be necessary to increase the weight of the bucket and to apply a certain number of tines. A tine, although pointed, has a thickness of $\frac{1}{2}$ or $\frac{3}{4}$ in. and a width of 1 or $1\frac{1}{4}$ in. It is obvious, however, bearing in mind the extent of the cutting edges of a bucket, that a tine, having a penetrating area of, say, less than 1 sq. in., has a greater power of penetration than in a plate blade, whether corrugated or not. Moreover, the tine will increase the weight of the bucket, so as to keep it from slipping or scraping along the surface of the soil. The increase in weight of the half-tine grab over that of the plate bucket is from 20 to 30%, and that of the whole-tine grab is about 90 per cent. This increase in weight, which is necessary to withstand severe shocks, will also serve to increase the penetrating power in proportion.

Penetrating Power of Bucket when Closing.—Fig. 8 represents a plate bucket, where A B and A C, the length of which $= a$, are hinged at A, B, and C.

B D E and C D F are semi-cylindrical scoops, hinged at D, the radius being b. $W =$ gross weight of bucket. $f =$ total penetrating power of a scoop, supposed to be distributed only along the edge.

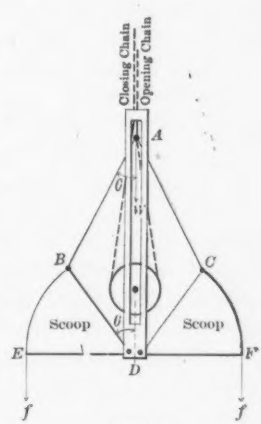

Fig. 8.

When the lifting chain of the crane is acting, the pin at H is pulled down by the closing chains, and the mouthpieces of the scoops tend to penetrate the earth, as long as the tension in the former chain is less than W, neglecting friction.

$$f = \frac{1}{2} W \frac{\sin.\ (\theta + \phi)}{\cos.\ \theta},$$

$$\text{where } \sin.\ \theta = \frac{b}{a} \sin.\ \phi.$$

The work done by the mouthpiece traversing from ϕ_1 to ϕ_2.

$$\omega = \int_{\phi_1}^{\phi_2} f\, b\, d\,\phi = -\frac{1}{2}\, b\, \omega \left[\frac{a}{b} \sqrt{1 - \frac{b^2}{a^2}\sin.^2\phi} + \cos.\,\phi \right]_{\phi_1}^{\phi_2}$$

The space-average force will be

$$f_{mean} = \frac{\omega}{b\,(\phi_2 - \phi_1)} = -\frac{1}{2}\,\frac{\omega}{(\phi_2 - \phi_1)}$$

$$\left[\frac{a}{b} \sqrt{1 - \frac{b_2}{a_2}\sin.^2\phi} + \cos.\,\phi \right]_{\phi_1}^{\phi_2}.$$

ϖ or f_{mean} is maximum when a is greatest; but the usual proportion is $a = 1.5\, b$.

Substituting 15° for ϕ_1, 105° for ϕ_2, 3 ft. for a and 2 ft. for b, as found in a Priestman's bucket, we have

$$f = \frac{1}{2}\, W \left(\frac{\frac{2}{3}\sin.\,\phi\cos.\,\phi}{\sqrt{1 - \frac{4}{9}\sin.^2\phi}} + \sin.\,\phi \right).$$

$$\omega = 2.28\, W.$$

$$f_{mean} = 0.36\, W.$$

Again, tracing f,

$f = 0.21\, W$, when the bucket is fully opened;

$f = 0.6\, W$, when $B\,D$ is 1^x to $A\,B$;

$f = \frac{1}{2}\, W$, when $B\,D$ is horizontal;

$f = 0.37\, W$, when the bucket is closed.

Next, let K represent the linear velocity of the point A, which is uniform; then the linear velocity of B or C, called V, will be represented by the following equation:

$$V = K \left\{ \operatorname{cosec.}\phi - \frac{b}{\tan.\,\phi\,(a\cos.\,\theta + b\cos.\,\phi)} \right\}$$

$V = K$, when $B\,D$ is 1^x to $A\,B$.

$V = 0.83\, K$, when $B\,D$ is horizontal.

From these calculations, it will be seen that the penetrating force entirely depends upon the gross weight of the bucket, and the bucket, when closing, exerts a very poor force at the beginning, but a tolerable one at the end of the work, the latter being necessary in order to close the bucket tight. The weight, however, cannot be increased, as it would cause a great loss of work in raising the bucket, and, from the capacity of the bucket, the upper edge of each scoop

cannot be made to take the horizontal position, when the bucket is entirely opened. Thus, it may often happen that a bucket working in hard soil closes itself, merely scraping the surface.

The writer, finding that the Priestman's plate bucket, newly armed with outside tines, or even the half-tine grab cannot work well in fine sand, used a "loosing" method, as he called it. When the bucket is dropped, a slight pull is given to the lifting chain, which is soon let go. Repeating this two or three times, the surface is sufficiently loosened to allow the mouthpieces to exert a greater penetrating force. The effect is good, any loss of time being compensated by certainty of action, the bucket being full or nearly so. But this method is not advisable for common use on account of great wear on the friction rollers.

Opening and Closing Methods.—There are two methods of opening and closing buckets; one by a single chain, and the other by double chains. The Gatmell or some other primitive single-chain bucket has to be laid on a platform before it can be discharged, and the discharge has to be made by an attendant. But under the Wild's or Cole's patent, an ingenious arrangement of dogs and disengaging apparatus is used to work quite automatically. In this method, however, the apparatus necessitates lifting the bucket to a certain fixed height at each dip, even when coming up empty, in order that the dogs may enter the disengaging ring to effect the opening of the bucket previous to the next descent. The lifting height cannot be adjusted in accordance with the free board of a barge which is being loaded. When dredging where pile stumps and wreckage prevail, this defect often necessitates either sending a diver below to open the bucket, or the use of a special arrangement of chain slinging. Moreover, the dog sometimes becomes clogged with dirt and grit, and refuses to act, preventing the bucket from closing. These drawbacks are obviated in the Priestman's or Morris and Cuming's bucket by using two chains in connection with the machine, one chain to open the bucket and the other to close it. One defect in this system is that the apparatus cannot be worked by an ordinary crane, but requires a special crane fitted with two chain barrels, as in the Morris and Cuming's dredge, or with a counterweight, as in the Priestman's dredge, for working a second chain. The depth at which this arrangement can operate the bucket is limited, and any

increase of depth would cause a great alteration. The complication of the crane requires greater skill to operate it; but when the operator is accustomed to it, it is quicker in motion than the single-chain crane, which has more motions to make in discharging. Mr. J. L. Stothert, as one of the judges to examine the dredging appliances at Tynemouth Exhibition, stated that the Priestman's dredge was much in advance of the others, notwithstanding that he was a member of a firm that had a special dredge of its own: the Wild's patent.

Guide-Frame, Poles, Spear, Cylindrical Weight, etc.—The cross-head, which is connected to the links of a bucket, is so constructed as to slide in a guide-groove, in the Priestman's dredge, or sometimes in a single-chain dredge. This guide acts like a diagonal line in a quadrilateral, and transmits equal force to each of the two halves of a bucket, when opening and closing. Without this, each scoop of a bucket is liable to trace unequal lengths of path; and, moreover, the bucket is obliged to have its chain barrel shaft in the same position with the connecting pins of the two halves, which causes the barrel to be buried in mud, so that it does not work smoothly. The Dick, Kerr and Co.'s double-chain bucket is without this contrivance. To obviate this defect, Mr. Cockburn adopted a guide tube, which slides in the catch of a single-chain bucket, and through which the closing chain works.

Bruce and Batho's dredge is furnished with a spear, which, according to Mr. George Boswell, is to keep the bucket mouth vertically downwards; without it the bucket, when in contact with an uneven bottom, would turn over on one side, and as a natural consequence would come up empty. It consists of a tapered spruce pole about 50 ft. long and works loose through thimbles at the jib end. The guide-poles attached to the frame of the bucket in American dredges are said to be used for similar purposes; but they will also guide the bucket to prevent its revolving around the lifting chain and giving torsion to the chain. No doubt, when the bucket is cutting into the material, the spear and the guide-poles will add much to the efficiency of the machine in shallow water; but where there is any considerable depth of water, the extra weight will more than counterbalance any gain in the dredging capacity.

Sir John Coode designed a patent cylinder-sinking grab for increasing its penetrating power. The grab is fitted with a patent

circular guard, which forms a guide in the cylinder. It is also furnished with the double system of tines, which work with a peculiar "pick-and-shovel" action, both digging up the bottom and breaking down the side material in a most effective manner. At Casteries Harbour, St. Lucia, where these grabs were used for putting down concrete cylinders, stiff clay was penetrated with results such as had never been achieved by any other grab.

Crane.

Much depends upon the lifting power available, for the larger the capacity of the dredge, and the more cohesive the earth to be excavated, the more power is necessary in the lifting apparatus. The excess of power, according to Mr. Newman, may be as much as three times the weight of the excavation to be lifted, for the weight of the bucket and the adhesion of the earth are to be resisted. To overcome these forces, and also to maintain a high rate of speed, the ample margin given in Table 8 is allowed in the lifting power of the crane by Stothert and Pitt.

TABLE 8.

Capacity of bucket, in cubic yards	¼	⅓	½	¾	1
Approximate quantity of mud lifted per hour, in tons	12	16	25	35	50
Weight of plate bucket, in hundredweights	12	19	23	26	30
" " half-tine grab, in hundredweights	14	25	27	34	40
Weight of whole-tine grab, in hundredweights	—	35	42	48	55
Weight of material in bucket, in hundredweights	7½	10	15	22½	30
Pull required on chain, in tons	1½	2	2½	3½	5
Nominal power of crane, in tons	2	3	5	7	10

The ordinary crane is fitted with double cylinders. The boiler is usually of the cross water-tube type, which requires less care and attention than any tubular boiler when using dirty or salt water. Its working pressure is commonly 75 lb. per sq. in. It stands on a tank, from which the feed-water is drawn by a pump

driven direct from one of the engine cross-heads. The cover of the tank forms a platform for the driver and the floor of a coal bunk. The boiler and tank act as a counterweight when the crane is loaded. The driver's position should be such that he can take a clear view of the work to be done, as well as of the engines and gearings. The operating levers should all be brought together, and so arranged that the driver has thorough control with the least amount of exertion.

The superstructure is carried on four rollers, or sometimes on two, which rest on the roller path, a solid or a loose ring. The resistance due to the friction of the ring upon its seat should be ample to allow the crane to be turned or slewed at a rapid rate, but not sufficient to permit the breakage of any of the teeth of the gear, if the engine be suddenly started, stopped or reversed, or the swinging of the crane be by any means arrested. The slewing motion should be such that the crane may swing in either direction without reversing the engines. The derrick gear, though not common in dredges, should be worked by worm and wheel, with safe arrangement to prevent the jib's running down.

A roof of light structure, covered with sheet iron, to protect the mechanism and the operator, will be of great service in exposed situations. In cold climates a considerable economy in the consumption of fuel is effected by covering the boiler with hair felt and wood lagging, over which is placed a casing of sheet iron, whilst in hot climates it is indispensable to the driver's comfort.

Table 9 is a table of cranes made by Messrs. Stothert and Pitt.

TABLE 9.

Power of crane, in tons	2	3	4	5	10
Radius of jib, in feet	14	16	16	16	16
Diameter and stroke of cylinder, in inches	5½x9	6½x9	9x10	9x10	9x12
Approximate weight, in tons	7½	11	13	15	20

The radius of the jib should be such that the bucket can discharge and distribute its contents over a barge to be loaded.

In the Priestman's dredge, the chain barrel is worked by friction rollers, which are set in contact by means of an eccentric. A special counterweight is used to bring back the small chain, when the bucket

is being lifted. The bucket is opened by holding that chain with a brake and letting go the larger chain.

Some American or so-called "clam-shell" dredges have two working drums, one for hoisting and one for lowering chains. The drums are supplied with friction gear, so that the engine does not require to be reversed, the weight of the bucket being sufficient to lower it when the friction gear is thrown out. The dredges have independent booms and stays.

Similarly, in a self-propelling dredge it is usual to have an independent boiler of the marine type, and in this case the crane is to be provided with a counterweight, fixed or adjustable.

The common dredge has a lifting velocity of about 100 ft. per min., and a slewing velocity of about 20 sec. for one complete revolution, the bucket being fully loaded. In 10 to 20-ft. depths of water, a skilful driver is said to make one dip per min. Now, assuming the lowering velocity to be equal to the raising velocity and that one-half revolution is necessary for discharging, the number of minutes required to make one dip in any depth will be represented by the following:

$$T = \frac{1}{3} + 0.02\,d + C.$$

T = number of minutes for one dip,

d = height to be raised, in feet,

C = number of minutes required for opening and closing the bucket and also for working the necessary handles, which is about one-third for a skilful driver.

$$\text{Thus, } T = \frac{2}{3} + 0.02\,d.$$

Barge.

The dredge can be readily put afloat by simply mounting it on any pontoon or barge of sufficient stability. The following dimensions for buckets are suggested by Messrs. Stothert and Pitt:

Size of bucket, in cubic yards	$\frac{1}{2}$	$\frac{3}{4}$	1	$1\frac{1}{2}$
Length of barge, in feet	35	40	50	60
Breadth " " " "	15	20	25	25
Depth " " " "	5	5	6	$6\frac{1}{2}$

For the Osgood dredge the following dimensions seem to be used commonly:

Size of bucket, in cubic yards	3	5	7
Length of barge, in feet	100	100	100
Breadth " " " "	30	35	40

The Priestman's standard sizes for barges are as given in Table 10.

TABLE 10.

Type.	Z.	Y.	A.	B.	C.	D.
Capacity of bucket, in hundredweights	$2\frac{1}{2}$	5	10	20	30	40
Capacity of crane, in tons	$\frac{3}{4}$	$1\frac{1}{4}$	$2\frac{1}{2}$	4	6	8
Radius of jib, in feet	12	14	18	18	18	18
Length of barge, in feet	30	38	45	50	55	60
Breadth " " " "	12	14	15	19	21	22
Depth " " " "	$3\frac{1}{2}$	$4\frac{1}{4}$	$4\frac{1}{2}$	5	$5\frac{1}{2}$	6

A square pontoon of timber or iron, with a circular end, over which the crane will work, makes the best and steadiest platform for the crane, but ordinary barges, well balanced, will answer the purpose in narrow canals, and when the dredge must pass through locks, the required stability may be given to the barge, when at work, by attaching a pair of timber or iron pontoons to each side.

For temporary work, a crane with all motions can be put on the barge, even without removing the wheels, if the amount of work to be done is small; or the wheels and axle boxes can be taken away, and the wrought-iron frame be bolted down securely to the deck or to some beams carried up from the floor of the barge, the center of the crane to be near one end of the barge, so that the dredge can cut its own flotation and work at each side and around the end, or dredge over the end and deliver into a barge at one side, or, in narrow canals and rivers, directly on the banks.

For permanent use, the vessel should be built of iron, with properly designed hull, having a suitable hopper well, with a capacity proportioned to the size of the bucket, the crane without a boiler to be placed forward, and the vessel to be fitted aft with the ordinary inverted engines and marine boiler. Such a dredge will be able to fill its own hopper, and, if necessary, one or more barges, and then tow away to sea for discharging.

Performance.

For the dredging work at Hakodate Harbour two Priestman's "D" type dredges were used, the radius of the jib being 18 ft., and the dredging depth 32 ft. below water level. The barge has the following dimensions: 64 by 22 ft. by 5 ft. 10 in.

The tidal range at the harbour is 2 ft. 8 in. The site to be dredged was originally 14 ft. 6 in. in depth, and was to be dredged to 24 ft. 6 in.

The bottom consists of two layers of soil: the first layer, which is about 3 ft. in thickness, consists of 15% mud and 85% sand; and the second of 10% mud, 84% sand and 6% shell. At the mouth of the dry dock the soil is somewhat different, being 10% mud, 80% sand, 4% shell and 6% round pebble. For dredging such hard earth, whole-tine grabs were used. The two dredges worked in the harbour, 1 200 ft. off the dock, in 1900, and at the mouth of the dock in 1901.

The following shows the cost of dredges:

Two dredges received at Yokohama	25 816.93	yen
Freight and insurance of the transport from Yokohama to Hakodate	2 141.802	"
Two barges	12 831.73	"
Total	40 790.462	"

Tables 11 and 12, given by Mr. Tsujimura, represent the working hours and running expense during the short interval specified.

In the Osaka Harbour Works, 5 Priestman's "B" type dredges are being used. The capacity of the bucket is 20 cwt. The crane can lift 4 tons, with a radius of the fixed jib of 18 ft. The barge is 54 ft. 6 in. long, 22 ft. wide and 6 ft. deep, having a mean draft of 2 ft. 6 in. The crane is mounted on the stern of the vessel. The dredging depth was originally 25 ft., but was increased to 35 ft. below water level in 1902. This alteration was made by changing the diameter of the chain barrel from 11¼ to 13½ in., the counterweight from 1 760 to 2 300 lb., and elevating the height of sheaves of the smaller chain. The dredges are called "*Asahigata.*" The depth of the site to be dredged varies from 0 to 6 ft. below low water, and it is intended to deepen it to 10 ft.

TABLE 11.

Year.	Month.	Number of days.	Number of hours.	Time Lost, Due to						Dredging hours.	Quantity Dredged. Tsubo.*		
				Weather.	Repairs.	Cleaning.	Waiting for barge.	Other causes.	Total.		Total.	Per working hour.	Per dredging hour.
				h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.			
1900	May	62	744	115 25	93 05	12 00	....	36 20	256 50	487 10	408	0.55	0.84
	June	60	720	50 00	16 00	31 15	....	17 30	114 45	605 15	559	0.78	0.92
1901	Jan.	62	744	148 40	4 21	29 00	188 20	72 00	442 20	301 40	289	0.39	0.96
	Feb.	56	672	213 20	14 10	....	110 10	24 00	361 40	310 20	314	0.57	1.00
	March	62	744	121 50	1 20	13 30	184 55	....	321 35	422 25	397	0.53	0.90
Total		302	3 624	649 15	128 55	85 45	483 25	149 50	1 697 10	2 126 50	1 967	0.54	0.93
Average per dredge per day		1	12	2 9	0 26	0 17	1 36	0 30	4 58	7 20	6.5	0.56	0.93
Percentage		....	100	17.9	3.6	2.4	13.3	4.2	41.4	58.6	....	....	....

*1 tsubo = 8 cu. yd.

TABLE 12.

Year.	Month.	Number of days.	Wages. Yen.	Coal. Tons.	Coal. Cost. Yen.	Other Expenses. Yen.	Depreciation of 10 per cent. Yen.	Interest of 5 per cent. Yen.	Total. Yen.	Unit cost per tsubo. Yen.
1900	May	62	198.29	20	160.00	73.31	339.92	169.96	941 48	2.31
	June	60	190.99	25	190.00	69.37	339.92	169.96	960.24	1.72
1901	Jan.	62	226.53	10	81.00	73.92	339.92	169.96	891.34	3.08
	Feb.	56	182.38	20	162.00	56.22	339.92	169.96	910.48	2.90
	March	62	231.53	20	162.00	81.00	339.92	169.96	984.41	2.48
Total........		302	1 029.72	95	755.00	353.82	1 699.60	849.80	4 687.95	2.38*
Average per dredge per day........		1	3.41	0.03	2.50	1.17	5.63	2.81	15.52	......
Percentage....		....	22.0	......	16.1	7.5	36.3	18.1	100.0	......

The crew consisted of 1 chief engineer, 2 second engineers, 2 firemen and 2 sailors.
1 yen = 50 cents.
*2.38 yen per tsubo = 14.9 cents per cu. yd.

The upper 2 or 3 ft. of the bed consist of fine sand, which is very difficult to dredge. The next 3 or 5 ft. consist of mud mixed with fine sand. Below this is a soft mud. In 1898 the dredge used plate buckets, except two, which had half-tine grabs. In 1899 all used plate buckets furnished with outside tines; in some cases, however, half-tine grabs were used whenever coarse sand or gravel was found. The maximum tidal range in this harbour is 6 ft. 6 in.

The *Asahigata* Nos. 1, 2, 3 and 4 began work April 18th, 1898; No. 5, July 11th, and No. 6, August 1st. The machine of No. 1 was replaced by a common crane and used for other purposes after October 31st, 1899.

The dredging site was open to the sea; so that when south or west winds prevailed the dredges had to be towed into the refuge place.

The cost of the plant was as follows:

The Priestman dredge, "B" type, with one extra plate bucket, received at Osaka........................6 533.333 yen
Wooden barge, including the mounting of the machine.3 321.40 "

Cost of one dredge............................9 854.733 "

Besides this, 2 extra grab buckets were supplied, each costing 975 yen.

Tables 13 and 14 represent the working and running cost of the dredges.

The dredging capacity, as can be seen, increases year by year, the driver becoming more skillful by practice. The working cost, on the contrary, decreases each year. To the premium given in the table, the writer will refer later.

Concluding Remarks.

The cost of working does not increase with the dredging depth, for a dredge of this type can be efficiently used at any ordinary depth with but little additional expense. However, it is generally agreed that the shape of the bucket has much to do with the success or failure of the apparatus.

For removing cohesive or hard compact soil, ordinary buckets have too much surface to penetrate the earth readily, and may be unable to do so. Fine sand or even coarse sand, if under a considerable head of water, may be difficult to penetrate with ordinary scoops, which may not bite or enter sufficiently to enable the bucket to gather its proper quantity of soil, and it then often merely scrapes the surface. Boulders are also difficult to dredge, one piece only being lifted, if it be caught at the joint where the two halves make contact. The bucket is often apt to tilt and become ineffectual, if a small piece of rock happens to get under the cutting edge. Grabs, therefore, together with other special appliances, are required to plow the soil.

The means of lowering, closing and raising a bucket or grab have been well considered, and it is in the direction of increased efficiency of the cutting and breaking apparatus, so as to feed the bucket or grab, and cause it to fill quickly and easily, that the greatest scope for improvement exists.

Experience points to the advisability of an effective use of a mechanical tool, such as a cutter or jumper, to disintegrate the material, and then of a grab or bucket to raise the loosened soil, rather than to attempt to excavate, collect, and raise the material with one machine at one operation.

TABLE 13.—PERFORMANCE OF PRIESTMAN'S "B" TYPE DREDGES.

Fiscal year.	Number of days.	Number of working hours.	Time Lost, Due to											Dredging hours.	Quantity Dredged. Tsubo.			Average quantity per working hour. Tsubo.	Average quantity per dredging hour. Tsubo.
			Steaming.	Towing out to site.	Shifting moorings.	Weather.	Repairs.	Towing into refuge.	Feeding water.	Waiting for barge.	Cleaning.	Other causes.	Total.		Ten-tsubo barge.	Smaller barge.	Total.		
		h. m.	h. m.	h. m.	h. m	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.					
1898....	1 169	12 097 25	1 557 00	57 20	101 45	142 10	414 05	......	223 05	493 45	611 40	682 00	4 292 50	7 804 35	......	18 803	18 803	1.55	2.41
1899....	1 946	21 445 00	1 929 20	21 20	171 30	2 251 50	4 238 40	9 00	226 20	591 10	1 277 50	326 50	11 043 50	10 401 10	421	22 499	22 920	1.07	2.20
1900....	1 753	19 618 20	1 996 00	83 20	268 20	2 426 50	2 034 50	43 00	288 10	697 00	1 184 30	191 00	9 213 00	10 405 20	1 460	26 843	28 307	1.44	2.72
1901....	1 760	20 070 20	1 768 00	356 30	187 50	2 386 00	3 396 20	267 00	121 30	441 20	1 039 10	167 50	10 131 30	9 938 50	12 807	21 592	34 399	1.71	3.46
1902....	1 775	20 264 30	1 848 00	368 10	640 10	2 558 00	2 667 20	164 00	10 50	501 30	897 00	842 30	10 497 30	9 767 00	10 380	29 176	39 556	1.95	4.05
1903....	1 765	20 237 10	1 652 00	44 50	519 30	3 355 50	3 273 00	62 40	13 50	648 30	963 40	591 50	11 125 40	9 111 30	11 782	28 677	40 459	2.00	4.44
Total..	10 168	113 732 45	10 750 20	931 30	1 889 05	13 120 40	16 024 15	545 40	893 45	3 373 15	5 973 50	2 802 00	56 304 20	57 428 25	36 854	147 590	184 444	1.62	3.21
Average per dredge per day.......		11 11	1 04	0 05	0 11	1 17	1 35	0 03	0 05	0 20	0 35	0 17	5 32	5 39	......	....	18.14	......	......
Percentage..		100.00	9.45	0.82	1.66	11.53	14.10	0 48	0.79	2.97	5.25	2.46	49.51	50.49	......	....	....	......	......

1 tsubo = 8 cu. yd.
The amount is measured by barge and is calculated to be $1\frac{1}{2}$ times place measurement.

TABLE 14.—RUNNING EXPENSE FOR PRIESTMAN'S "B" TYPE DREDGES.

Fiscal year.	Number of days.	LABOUR. Number of crew.	LABOUR. Salaries. Yen.	LABOUR. Boarding. Yen.	LABOUR. Premium. Yen.	LABOUR. Total. Yen.	MATERIALS. Coal used. Pounds.	MATERIALS. Cost of coal. Yen.	MATERIALS. Oil, etc. Yen.	MATERIALS. Other expenses. Yen.	MATERIALS. Total. Yen.	Repairs. Yen.	Depreciation of 10 per cent. Yen.	Interest of 5 per cent. Yen.	Total. Yen.	Unit cost per tsubo. Sen.
1898....	1 672	7 822	3 628.365	....	....	3 628.365	742 750	2 821.564	295.402	831.973	3 948.939	2 077.861	5 435.480	2 717.740	17 808.385	94.7
1899....	2 089	10 360	4 350.204	1 170.660	361.271	5 882.135	962 950	3 592.583	481.150	1 057.479	5 131.212	3 204.701	5 608.059	2 804.080	22 630.137	98.7
1900....	1 825	9 091	3 949.044	1 156.560	1 116.052	6 221.656	923 350	3 164.774	356.538	1 043.775	4 565.087	4 426.858	5 024.867	2 512.433	22 750.901	80.4
1901....	1 825	9 046	4 056.858	1 169.870	1 804.488	7 031.216	1 001 700	4 100.719	494.341	994.013	5 589.073	7 424.936	5 024.867	2 512.433	27 582.525	80.2
1902....	1 825	9 051	4 064.660	1 166.110	2 600.248	7 831.018	1 111 900	3 346.170	327.896	100.282	3 774.348	7 490.152	5 024.867	2 512.433	26 632.818	67.3
1903....	1 830	8 887	3 991.630	1 145.710	2 612.092	7 749.432	1 157 000	2 809.142	407.644	75.590	3 292.376	8 389.251	5 024.867	2 512.433	26 968.359	66.7
Total..	11 016	54 257	24 040.761	5 808.910	8 494.151	38 343.822	5 899.650	19 834.952	2 362.971	4 103.112	26 301.035	33 013.759	31 143.007	15 571.502	144 373.125	78.3*
Average per dredge per day.		4.9	2.182	0.527	0.771	3.480	535.5	1.801	0.215	0.372	2.388	2.997	2.827	1.414	13.106	......
Percentage...		......	16.65	4.02	5.89	26.56	....	13.74	1.64	2.84	18.22	22.87	21.57	10.78	100.00	......

The fiscal year begins April 1st. The number of days in Table 13 does not include holidays and those during which the dredges were used for other purposes.

1 yen = 50 cents.

The cost of transportation is not included in Table 14.

*78.3 sen per tsubo = 4.9 cents per cu. yd.

Ladder Dredges.

The essential apparatus of the ladder dredge is an endless bucket chain, which turns around two tumblers placed at the extremities of a ladder. The ladder is composed of metallic girders, connected to the top of a frame by a shaft, which permits the girder to revolve so as to change the position of the lower end.

Generally speaking, the dredge is adapted to homogeneous material, and where a regular cut can be taken over a large area. Hard soil, however, presents no obstruction to this type of dredge, provided it is constructed with sufficient strength. The great power and strength of the machines enable them to work in any kind of soil that can be penetrated or excavated by mechanical means. It is only a question of strength of the apparatus and steam to overcome resistance. In some dredges, the power of the engines limits the strain on the bucket chains, and they are made sufficiently strong to withstand safely any resistance with the throttle wide open and full pressure of steam.

This type is a favorite in Europe, though not so popular in America. In dredging, it is necessary to give sufficient pull to the front chain, or to force the cutting edges of the buckets into the material to be dredged, causing them to penetrate partly by their weight, and partly by the mooring chain. When working in a channel or a narrow space the mooring chains cause some restraint to navigation. It is not generally adapted to work at the entrance of a harbour or other exposed site, because heavy waves cause violent shocks to the ladder on account of its rigid connection. When the wave height is more than 2 or 2.5 ft., it becomes dangerous to work with this type of dredge. Moreover, it has the great disadvantage of having to lift the spoil to a height much greater than required for discharging it into the hopper well or barges.

Hull.

The form of the hull depends entirely upon the condition of the work. The length is closely related to the dredging depth, and also to the capacity of the spoil well, if any. When the dredge has to pass through a narrow dock entrance, or other openings, its width is limited. When it has to work in an open sea it should be wide. These conditions, together with the working capacity and the depth

of the site, will affect the depth and also the draft. The frames, their pitch, plating, etc., are, of course, to be proportioned to the work. The hull of the dredge is generally made of iron or steel, but steel is preferable for the bottom plating, as it is sometimes exposed to grounding.

Stationary Barge-Loading Dredge.—This dredge is usually of small capacity and used only in calm water, as in a canal or river. The vessel is lightly constructed, with a flat bottom, the material being steel, iron or sometimes wood. Table 15 gives some existing examples from which the following relations, which will suggest the usual proportions of the dimensions of the hull, are obtained.

$$\frac{\text{Length}}{\text{Dredging depth}} = 3.0 \text{ to } 5.0$$

$$\frac{\text{Breadth}}{\text{Length}} = 0.2 \text{ to } 0.3$$

$$\frac{\text{Depth}}{\text{Length}} = 0.075 \text{ to } 0.12$$

$$\frac{\text{Draft}}{\text{Length}} = 0.035 \text{ to } 0.06$$

$$\frac{\text{Length} \times \text{Breadth} \times \text{Draft}}{\text{Hourly dredging capacity}} = 1.2 \text{ to } 2.5$$

Self-Propelling Barge-Loading Dredge.—This kind of dredge has a moulded hull, like that of a cargo boat, and is so constructed as to be able to navigate in an open sea with a velocity of from 6 to 10 knots. It is commonly used for the up-keep of ports or channels of estuaries, where barge loading can be done safely in calm weather, but occasional swells necessitate the dredge's retiring to headquarters. It can also be used to tow the barges, if necessary. The dredging capacity is much greater than that of a stationary dredge.

Some existing examples are shown in Table 16.

The relations are as follows:

$$\frac{\text{Length}}{\text{Dredging depth}} = 4.3 \text{ to } 5$$

$$\frac{\text{Breadth}}{\text{Length}} = 0.18 \text{ to } 0.23$$

$$\frac{\text{Depth}}{\text{Length}} = 0.07 \text{ to } 0.075$$

$$\frac{\text{Draft}}{\text{Length}} = 0.045 \text{ to } 0.055$$

TABLE 15.—Showing Comparative Proportions of Various Ladder Dredges.

Dredge.	*Nos. V and VI.*	*Asanagi and Yunagi.*	*Von Dömming.*	....	....	....	*Nearchus.*	*No. 2.*	*No. 3.*
Destination.	Yodogawa, Japan.	Osaka.	Stralsund.	Loire.	Vienna.	Toulon.	Karachi.	Tees.	Tees.
Length, L	59-0	79-5	95-1	105-0	88-7	108-3	160-0	112-0	125-0
Breadth, B	15-0	23-11	27-11	23-7	19-8	21-4	28-0	29-0	34-0
Depth, D	7-2	7-10	10-10	8-2	7-10	8-6	11-0	9-0	9-6
Draft, Dt	3-1	3-5	4-7	4-7	3-11	3-11	10-0	....	....
Dredging depth, Dd	6-0	15-0	20-4	29-6	23-0	62-4	32-0	....	....
Bucket capacity. Cubic feet	4	6.5	6.4	8.8	8.8	8.8	9	9	9
Bucket velocity	16	16	18-24	16-17	....	....	12-15	....	....
Dredging capacity. Tons, C	100	200	246	213	....	....	300	....	....
I. h. p.	36	70	....	90	50	60	130	....	....
$\frac{L}{Dd}$	9.89	5.29	4.68	3.56	3.85	1.74	5.00	....	....
$\frac{B}{L}$	0.254	0.301	0.294	0.225	0.222	0.197	0.175	0.259	0.272
$\frac{D}{L}$	0.122	0.099	0.114	0.078	0.088	0.079	0.069	0.080	0.076
$\frac{Dt}{L}$	0.053	0.043	0.048	0.044	0.044	0.036	0.063	....	....
$\frac{L \times B \times Dt}{C}$	1.26	1.50	2.30	2.47	....	....	6.91	....	....

Dredge.	*No. 4.*	*No. 5.*	....	....	....	....	*No. 4.*	*Ichimatsu and Koroku.*	....
Destination.	Tees.	Tees.	Weser.	Ostend.	Panama.	Kaiser Wilhelm Canal.	Garonne.	Atsuta, Japan.	Stettin Swinmund.
Length, L	135-0	140-0	110-0	114-10	108-3	115-1	114-10	118-0	127-3
Breadth, B	34-6	34-6	20-0	19-8	21-4	19-8	26-3	23-0	29-6
Depth, D	10-6	10-6	8-6	8-10	8-2	9-10	10-10	9-2	8-10
Draft, Dt	....	....	4-11	3-11	4-3	4-5	7-5	4-3	5-11
Dredging depth, Dd	....	....	23-0	29-6	....	36-1	44-3	32-0	32-10
Bucket capacity. Cubic feet	9	9	10	10.6	12.4	13.5	14.1	15	12.4
Bucket velocity	....	....	13	14	....	13	15	16	12½
Dredging capacity. Tons, C	....	....	279	205	....	328	410	410	....
I. h. p.	....	....	90	150	80	150	160	125	150
$\frac{L}{Dd}$	....	....	4.78	3.89	....	3.19	2.59	3.69	3.89
$\frac{B}{L}$	0.255	0.247	0.182	0.171	0.197	0.171	0.229	0.195	0.232
$\frac{D}{L}$	0.078	0.075	0.077	0.077	0.076	0.085	0.094	0.078	0.070
$\frac{Dt}{L}$	....	....	0.045	0.034	0.039	0.038	0.065	0.036	0.046
$\frac{L \times B \times Dt}{C}$	....	....	1.76	2.00	... .	1.46	2.52	1.30	....

21.6 cu. ft. of the dredged material are supposed to weigh 1 ton, or the weight of 1 cu. ft. = 103.7 lb.
The length, breadth, depth, draft and dredging depth are given in feet and inches.

TABLE 16.—SHOWING COMPARATIVE PROPORTIONS OF SOME SELF-PROPELLING LADDER DREDGES.

Dredge.	*Amélie.*	*Dolphin.*	*Shinchiku.*	*Merak.*	*Ville de Rochefort.*	*Lyster.*	*Melbourne.*	*Andrée.*	....
Destination.	Boulogne.	Casteries, St. Lucia.	Keelun, Japan.	Batavia.	Charente.	Mersey.	Melbourne.	Le Havre.	Vladivostok.
Length, L	127- 5	130-0	140- 0	159-11	160- 2	196- 0	200-0	182- 0	164- 0
Breadth, B	24- 1	30-0	33- 0	30- 0	32-10	35- 6	35-0	33- 7	32-10
Depth, D	9- 2	8-0	15- 0	12- 0	11- 2	13- 0	11-6	13- 1	12- 6
Draft, $D t$	6-11	5-9	10- 0	7- 6	8- 2	....	9-0	8-10	8- 6
Dredging depth, $D d$.	28- 8	30-0	35- 0	27-11	32-10	45- 0	....	39- 4	35- 1
Bucket capacity. Cubic feet	10.6	7	12	12	26.5	20	21	26.5	21.2
Bucket velocity	....	....	12-18	13-14	15	15-10	....	....	....
Dredging capacity. Tons, C	164	200	400	360	574	400	800	574	820
Engine	....	2 compound.	2 compound.	....	2 compound.	2 triple.	2 compound.	....	2 compound.
Pressure. Pounds	....	90	100	....	114	180	90	....	105
Position of ladder	....	bow.	stern.	....	stern.	bow.	stern.	....	....
Number of propellers.	....	2	2	....	2	2	2	....	2
I. h. p	250	600	600	75	500	....	500	500	800
Velocity of vessel. Knots	5	7¼	6	6	6	10¼	7	7.5	8¼
$\frac{L}{D d}$	4.44	4.33	4.00	5.73	4.88	4.36	....	4.63	4.68
$\frac{B}{L}$	0.189	0.231	0.236	0.188	0.205	0.181	0.175	0.185	0.200
$\frac{D}{L}$	0.072	0.062	0.107	0.075	0.070	0.066	0.058	0.072	0.076
$\frac{D t}{L}$	0.054	0.044	0.071	0.047	0.051	....	0.045	0.049	0.052

The length, breadth, depth, draft and dredging depth are given in feet and inches.

Self and Barge-Loading Dredge.—This is a sea-going vessel, arranged to be used as a dredge as well as a barge. This is what chiefly distinguishes it from the barge-loading type. Its best field is where the depositing site is not more than three miles from the dredging ground. The advantage which the hopper dredge possesses over the ordinary dredge is that the first cost of plant is less, no barge being required. It is a convenient machine to operate in a

rough sea, where barges cannot be moored alongside. It can be advantageously used where, on account of great range of tide, or from other causes, dredging can be done during a portion of the tide only. In that case the vessel and the crew may be more economically employed in taking the dredged material out to sea and depositing it than in idly waiting for the time to resume work whilst the dredged material is being conveyed by other vessels and crews. In canals and narrow channels, where hoppers alongside a barge-loading dredge will be inconvenient, and in navigation of great length, where small quantities of dredged material might be required at intervals, the self-contained arrangement of the hopper dredge will be of advantage.

On the other hand, a hopper dredge, when going to discharge, has to transport the useless dredging apparatus, which is placed in a position unfavorable for maintaining the stability of the vessel. This inconvenience is seriously felt when the dredge has to travel a great distance in a rough sea for discharging. With a hopper dredge, dredging becomes more intermittent and irregular, and it is difficult, after each trip, to find the previous cutting front. There is a loss of time due to taking and dropping mooring chains when going to discharge; and, moreover, a long time is spent in navigating and discharging. The net dredging capacity is, therefore, greatly reduced. Hence, when the quantity of soil to be dredged is great, when many dredges are to be worked simultaneously, or when a large number of barges is at the service continuously, a hopper dredge is never used, except in an open sea, or when there are some special inconveniences. Moreover, it has a greater draft, so that it cannot be used in shallow water without danger of grounding, although it is constructed so as to be able to cut its own flotation.

There are some authorities who insist that a hopper dredge can work with a smaller number of men and the cost of dredging and transport is less than with a stationary dredge and barges. The first cost of plant is sure to be lower, but a greater efficiency and economy in dredging will be obtained with an ordinary barge-loading dredge supplied with barges. So it is yet to be proved that a vessel with a dead-weight of machinery, etc., considerably in excess of its cargo, and with a much larger crew than necessary for the purpose, can convey to sea a hopper load of dredged material at a

cheaper rate than a vessel having only a sufficient capacity and crew for its cargo.

TABLE 17.—SHOWING COMPARATIVE PROPORTIONS OF VARIOUS HOPPER DREDGES.

Dredge.	*Manche.*	....	*Shunkai, No. 1.*	*Shunkai, No. 2.*	*Pas-de-Calais.*	....	*William Price.*	*La Puissante.*
Destination.	Dieppe	Bulgaria.	Osaka.	Osaka.	Boulogne.	Bristol.	Karachi Port Trust.	Suez Canal.
Length, L	168	137-9	170-0	170-0	179-9	218-0	236-0	275-0
Breadth, B	30-2	27-3	33-6	36-0	33-2	48-0	42-6	47-0
Depth, D	14-0	12-2	14-3	15-0	14-0	17-0	16-0	19-0
Draft, light, D_0	8-8	....	9-3	10-0	9-6	10-6	....	....
Draft, loaded, D_1	12-4	....	11-6	12-6	12-2	14-6	....	16-5
Dredging depth, Dd	31-2	32-10	35-0	35-0	41-0	36-0	43-0	40-0
Bucket capacity. Cubic feet	12.4	8.8 and 13.4	17.	21.	11.3 and 17.7	17.7	22. and 12.	31.
Bucket velocity	16	....	16	12-18	10-15	16-18	....	18-20
Dredging capacity. Tons, Cd	328	590	600	600	492	1 000	1 250	1 150
Hopper capacity. Tons, Ch	525	500	600	600	525	1 000	....	2 200
Engine	....	1 compound.	2 compound.	2 compound.	....	2 triple.	2 triple.	2 triple.
Pressure. Pounds	....	103	120	150	....	140	160	160
Position of ladder	....	bow.	bow.	stern.	bow.	stern.	bow.	stern.
Number of propellers	....	1	2	2	2	4	2	2
I. h. p	500	....	650	500	660	1 300	1 840	1 620
Velocity when loaded. Knots	7.0	7.0	7.0	7.0	6.25	9.0	10.0	9¾
$\frac{L}{Dd}$	5.39	4.20	4.86	4.86	4.38	6.06	5.49	6.87
$\frac{B}{L}$	0.180	0.198	0.191	0.212	0.184	0.197	0.180	0.171
$\frac{D}{L}$	0.083	0.088	0.084	0.088	0.078	0.078	0.068	0.069
$\frac{D_1}{D}$	1.42	....	1.24	1.25	1.28	1.38	....	....
$\frac{D_{10}}{L}$	0.073	....	0.068	0.074	0.068	0.067	....	0.060
$\frac{Ch}{Cd}$	1.60	0.85	1.00	1.00	1.07	1.00	....	1.91

The length, breadth, depth, draft and dredging depth are given in feet and inches. The relations are given in Table 18.

Twin screws are adopted for a stern-well dredge, which has its ladder well in the stern, and a single screw, generally, for a bow-well dredge. The former gives a better form to the bow of the vessel,

and the stern, being large enough to shelter the propellers, necessitates the use of two rudders. This insures great maneuvering power and, at the same time, offers a great displacement for supporting a heavy bucket chain.

Examples of this type will be found in Table 17.

When the dredge is to work in a narrow canal or channel, it is sometimes constructed with four propellers, two in the bow and two in the stern, so as to develop equal speed ahead and astern. The four propellers necessitate the construction of shafting tunnels through the hopper, if any, which may be so arranged as to add materially to the strength of the vessel.

TABLE 18.

Proportion.	Stationary dredge.	Self-propelling barge-loading dredge.	Hopper dredge.
$\frac{L}{Dd}$	3.0 to 5.0	4.3 to 5.0	4.8 to 6.0
$\frac{B}{L}$	0.2 to 0.3	0.18 to 0.23	0.18 to 0.20
$\frac{D}{L}$	0.075 to 0.12	0.07 to 0.075	0.07 to 0.088
$\frac{D_1}{D_0}$	....	....	1.3 to 1.4
$\frac{D_1}{L}$	0.04 to 0.06	0.045 to 0.055	0.067 to 0.07
$\frac{Ch}{Cd}$	....	....	1.0 to 2.0

Engine and Boiler.

Engine.—The marine compound surface condensing engine is generally used for a common dredge. As the work of a dredge is quite variable, it is very necessary to have a superior and efficient engine. Hopper dredges with stern wells are usually provided with two compound surface condensing engines, sometimes with triple-

expansion engines. The ratio of i. h. p. to dredging capacity, in tons, varies greatly with the kind of dredge thus:

Kind of Dredge.	I. h. p. / Capacity, in tons.
Non-propelling	0.35 to 0.45
Self-propelling barge-loading	0.60 to 1.00
Self and barge-loading	0.80 to 1.50

The i. h. p. of a non-propelling dredge depends, of course, upon the work done in raising the soil and also upon the work done in overcoming the resistance of the earth. The resistance, however, being much greater, the i. h. p., roughly speaking, will have a certain ratio to the dredging capacity. As to the self-propelling dredge, it will have some relation to the displacement of the vessel, or to $(\text{displacement})^{\frac{2}{3}}$, not to the dredging capacity. That is why the ratio is much greater in a self-propelling dredge than in a non-propelling dredge. The following is a table of the power required for both dredging and propelling, as determined by the writer in his experiments at the Osaka Harbour Works:

Dredge.	I. h. p. when dredging with a velocity of 18 buckets per min.	I. h. p. when propelling with a velocity of 7 knots.
Shunkai No. 1	118.9	514.1
Shunkai No. 2	135.2	322.2

The power required for dredging varies with the kind of soil and also with the height to which the soil is raised, together with the friction of the machinery; so that it is very difficult to find a general expression for the horse power required. However, Mr. Molesworth proposed the following relation:

$$\text{i. h. p.} = C(0.004\,H + K),$$

where C = number of cubic feet dredged per minute,

H = height, in feet, to which the material is raised, that is, (height of the upper tumbler above water) + (dredging depth),

K = constant, = 0.35 for stiff clay and gravel, = 0.15 for soft clay and mud.

The writer took several indicator diagrams of the engines of self

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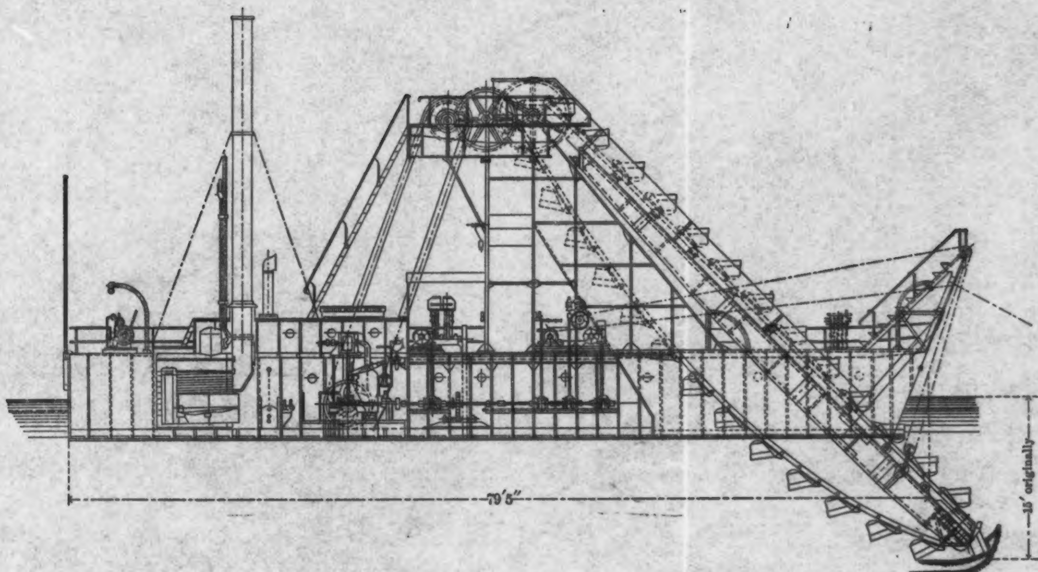
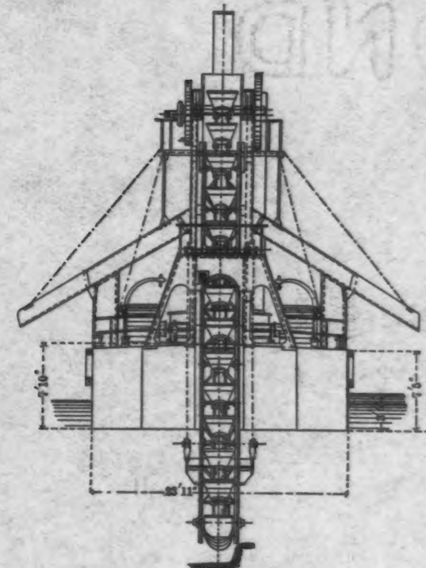
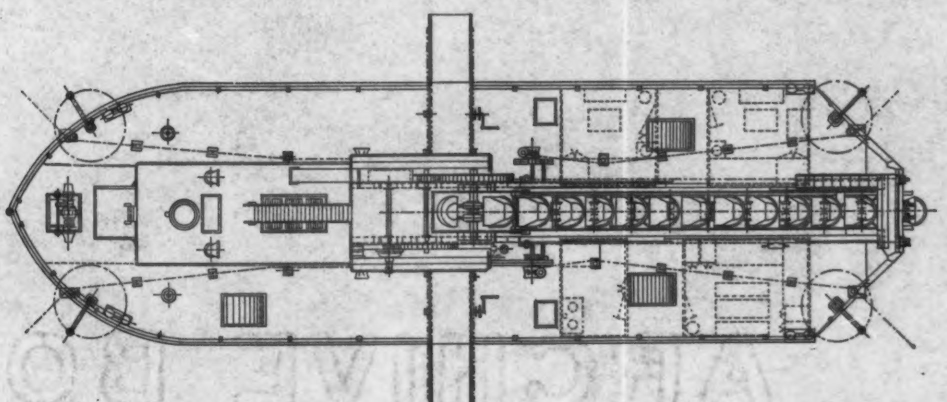






ASANAGI AND YUNAGI

Scale of Feet

0 5 10 20 30

and barge-loading ladder dredges of the Osaka Harbour Works. The heights of the upper tumblers are:

Dredge.	Height of upper tumbler above water.	Maximum dredging depth.
Asanagi and *Yunagi*......	26 ft. 6 in.	15 ft.
Shunkai No. 1..........	26 "	35 "
Shunkai No. 2..........	36 "	35 "

Each indicator diagram differs greatly from the others, on account of the irregularity of the bottom, the discontinuousness due to alternate bucket and link of the chain, and variation of moment of force, due to the square form of the upper tumbler, even when the nature of the soil, the dredging depth and the initial tension of the bucket chain remain the same. It is very difficult to find the true i. h. p. from such varying diagrams. But the writer observed that the absorption of the horse power of the machinery, when it is running light, is from 50 to 70% of the total i. h. p. exerted when it is fully loaded, while the theoretical horse power for raising the soil is only from 20 to 30% of the total i. h. p.

Now, treating the theoretical horse power for raising the soil as unity, horse power due to friction of machinery when running light = 2 to 3.

Horse power due to earth resistance and additional friction of machinery due to full load = 0.5 to 1.0 (the earth being mud or soft clay).

From the results, it will be seen that the ladder dredge has a very poor efficiency as a machine, and, moreover, that the material is lifted to a height nearly double that required. The first drawback comes from the rough structure of the bucket chain, and the second from the construction of the shoot. To reduce these disadvantages, the initial tension of the chain should be made as low as possible, and every part of the chain be well lubricated. The upper tumbler should be placed as low as possible, or the shoot should be dispensed with, if possible, and replaced by another discharging apparatus.

Boiler.—The boiler is commonly of the marine tubular type. One boiler is used for a dredge having a single boiler, and two, or sometimes three, for a dredge having a pair of independent engines. The boilers are so arranged that each may be worked independently of the others.

Transmission of Power.

Power is transmitted to the top tumbler supported on a strong solid frame, the height of which is determined by the easy discharge of shoots. The transmitting machinery must be simple in construction and elastic enough to resist shocks. Belting, shafting and pitch-chain gearing are resorted to. Whatever may be used, a frictional gearing must be interposed, to avoid the danger of fracturing any part of the machinery in case of a sudden shock received by coming in contact with unusually hard substances. The hydraulic clutch is commonly used on the German small dredge. Often the top tumbler shaft is driven by a surging wheel, the friction wave of which is so large that it does not interfere with the structural strength of the rim.

Belt gearing is practically noiseless and can be easily started and stopped. As the belt tensions are different in the driver and in the follower, slips occur, causing the follower to revolve at a slightly decreased rate. This gives a dredge an advantage in case of shocks. However, as it is difficult and expensive to use for heavy pressure, it is rarely used for a dredge with a large capacity.

Shafting is used in connection with spur gearing. It is practically noiseless, but considerable power is required merely to turn the shaft.

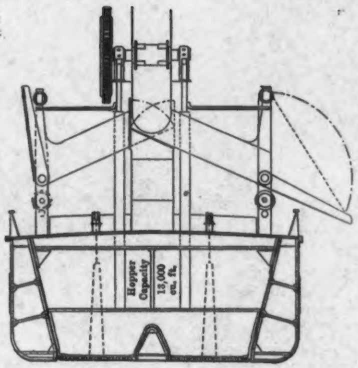
Spur-wheel gearing, on the other hand, is noisy, especially when reversed. The teeth are liable to break under shocks for lack of slip, unless a slipping clutch be introduced.

Pitch-chain gearing is as useful as belt driving, decreasing the number of working parts, while modifying the power. It provides positive transmission and may be used with a heavy load. It is much more elastic than shafting. Mr. Fred. Lobnitz prefers it to the others on account of its elasticity, and even in case of breakdown it is generally easier to repair than spur wheels. The increase of pitch after wear, however, causes excessive friction and bad working.

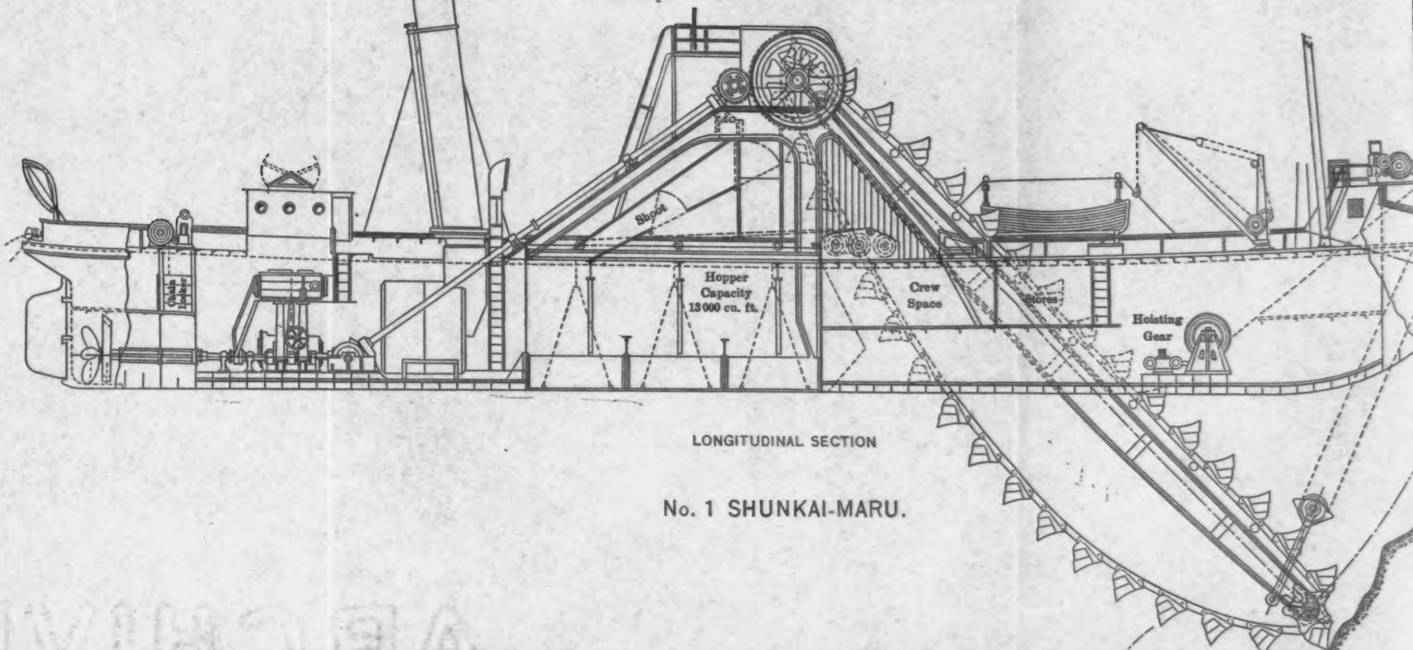
After all, since the introduction of cast steel, shaft gearing has been generally adopted for a large dredge, and belting for a medium-size dredge, while pitch-chain gearing is used only by some special dredge makers. Whatever means may be used for driving the tumbler, the most approved practice is to have two wheels on the top tumbler shaft so as to have equal torsion and smooth driving.

PLATE XX
TRANS.
INTER

CRANE A



SECTION THROUGH HOPPER



LONGITUDINAL SECTION

No. 1 SHUNKAI-MARU.

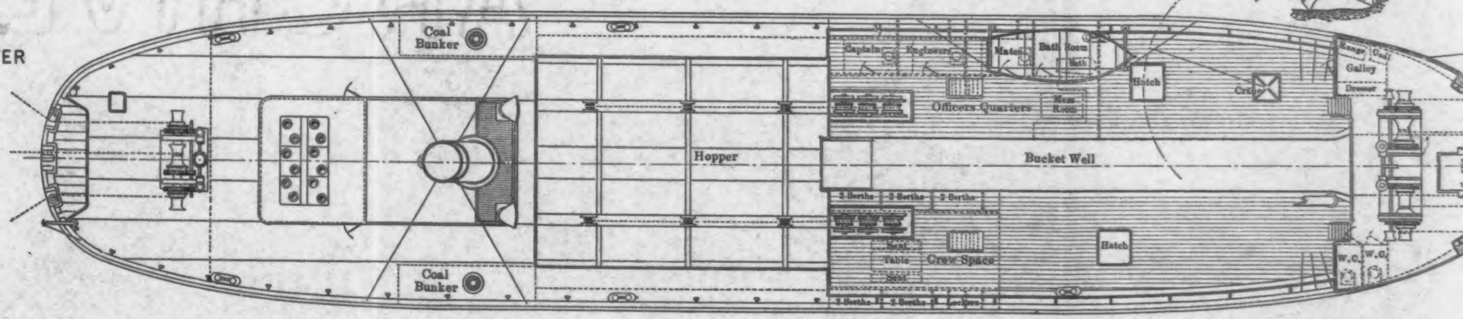
DIMENSIONS

Length between perpendiculars	170′ 0″
Breadth moulded	33′ 6″
Depth "	14′ 3″

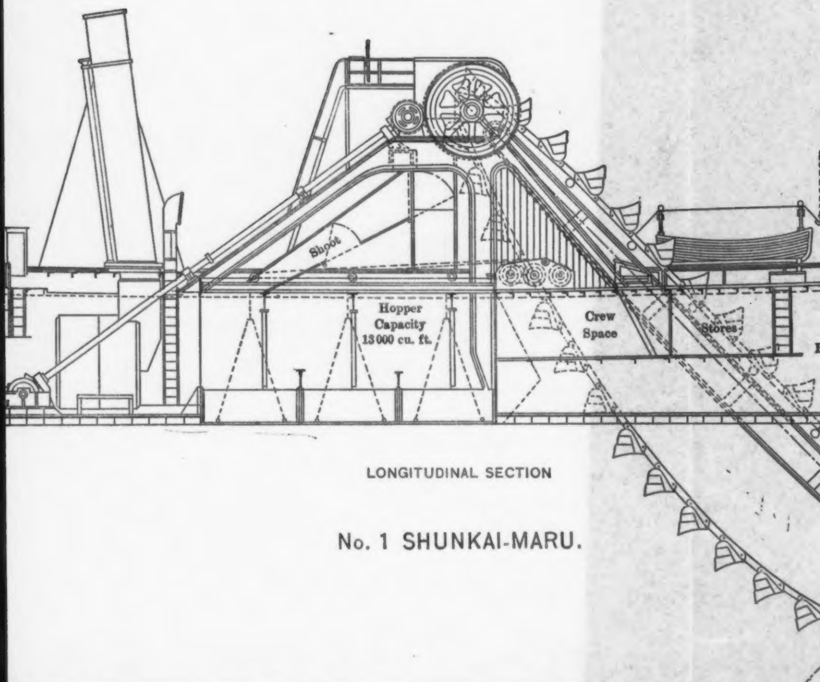
Scale of Feet

2 0 1 2 4 6 10 14 18

DREDGE TO 35 FEET DEPTH OF WATER

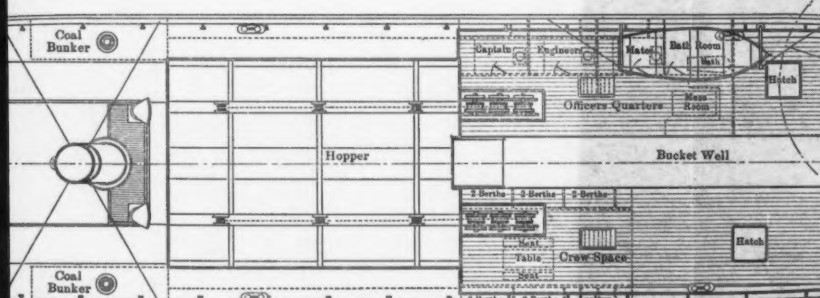


DECK PLAN



LONGITUDINAL SECTION

No. 1 SHUNKAI-MARU.



DECK PLAN

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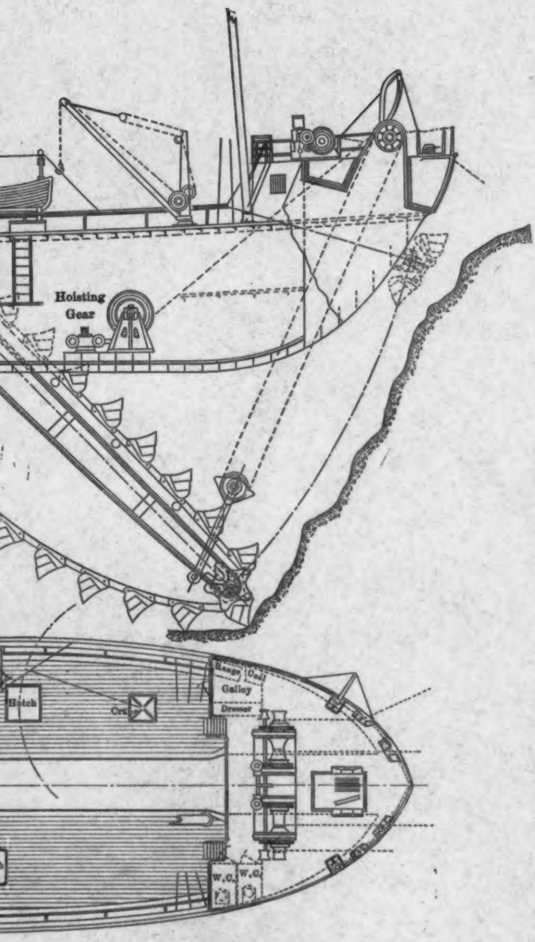


For the same reason, two sets of belt or pitch chains are to be used.

To make the tumbler revolve 7 or 8 times per min. a set of spur wheels and pinions is used. Some dredges are so constructed as to have different port and starboard engine gears, having different velocity ratios. This is necessary when the soil to be dredged is of variable nature. Sometimes the gearing which transmits the motion from the engine to the tumbler shaft is so arranged that the speed can be varied independently of that of the engine.

There is another method of power transmission, which answers well for some special requirements, and is proposed by Mr. Bates and Mr. H. F. Smulders, namely, electrical transmission.

The following advantages are claimed by Mr. Bates for electrical transmission used on dredges in harbours and canals:

1.—The hull of the dredge may be smaller, and the first cost, therefore, cheaper.

2.—The central station will serve to supply energy for other installations destined for the construction of quay walls, etc., if there be such. It may also be utilized for lighting the harbour, working cranes, and moving bridges, lock gates, etc., even after the dredging is finished.

3.—Every part of the mechanism of the dredge may be set in motion without delay, and the control is very perfect and easy.

4.—The power is transmitted by a cable, enclosed in a sheath forming a floater, which supports the cable on the surface of the water.

This method is useful where a group of non-propelling dredges and elevators are used; but it cannot be applied to self-propelling dredges, nor adopted at a site where obstruction to navigation is seriously felt.

Dredging Apparatus.

Bucket Chain.—There are two types of bucket chains: one is an open-connected type and the other a close-connected type. The former consists of buckets and links alternately connected, and is used for general work. The latter is a thorough connection of buckets only, and is used for specially soft and homogeneous mud. For dredging different kinds of soil, some dredges are constructed to have two sets of chains, which differ only in the bucket contents.

The velocity of the bucket chain is usually denoted by the number of buckets traversed per minute. It should be such as easily to give a regular and uniform feed of soil to the buckets, in order that they can, at all times, work to their full capacity without causing any severe strain. The velocity is now commonly from 14 to 18 buckets per min. for ordinary soft material, and from 10 to 13 for hard substances. Thus the linear velocity of the bucket chain will be proportional to the pitch of the link.

If the chain is open-connected, and used for soft material,

$$V = 2\,(14 \ldots\ldots\ldots\ldots 18)\,P,$$

where V = velocity per minute,

P = pitch of chain.

The bucket chain, as has been said, should have sufficient strength to withstand safely the immovable resistances encountered. The resistances, of course, varying with the nature of the soil, make it very difficult to determine the requisite strength of chain required. Table 19 gives some relations between the dredge capacity, bucket capacity, pitch of chain and the diameter of the pin, which have been successful in practice.

TABLE 19.

Dredge.	Destination.	Dredging capacity. Tons per hour.	Bucket Capacity. Cubic feet.	Pitch of chain. Inches.	Width of chain. Inches.	Diameter of pin. Inches.
Shunkai No. 1...........	Osaka.	600	17	33	$25\frac{3}{8}$	3
Shunkai No. 2...........	Osaka.	600	21	$39\frac{3}{8}$	$24\frac{3}{8}$	3
Shinchiku............	Keelun.	400	12	32	$17\frac{1}{2}$	$3\frac{1}{4}$
Koroku and *Ichimatsu*..	Atsuta.	400	15	$28\frac{3}{8}$	28	$2\frac{3}{8}$
Asanagi and *Yunagi*....	Osaka.	200	6.5	26	$14\frac{3}{8}$	$1\frac{3}{4}$
No. V and *No. VI*........	Yodogawa.	100	4	20	$11\frac{3}{8}$	$1\frac{1}{4}$

Thus bucket capacity, in cubic feet $= \left(\frac{3}{100} \text{ to } \frac{4}{100}\right)$ dredging capacity in tons.

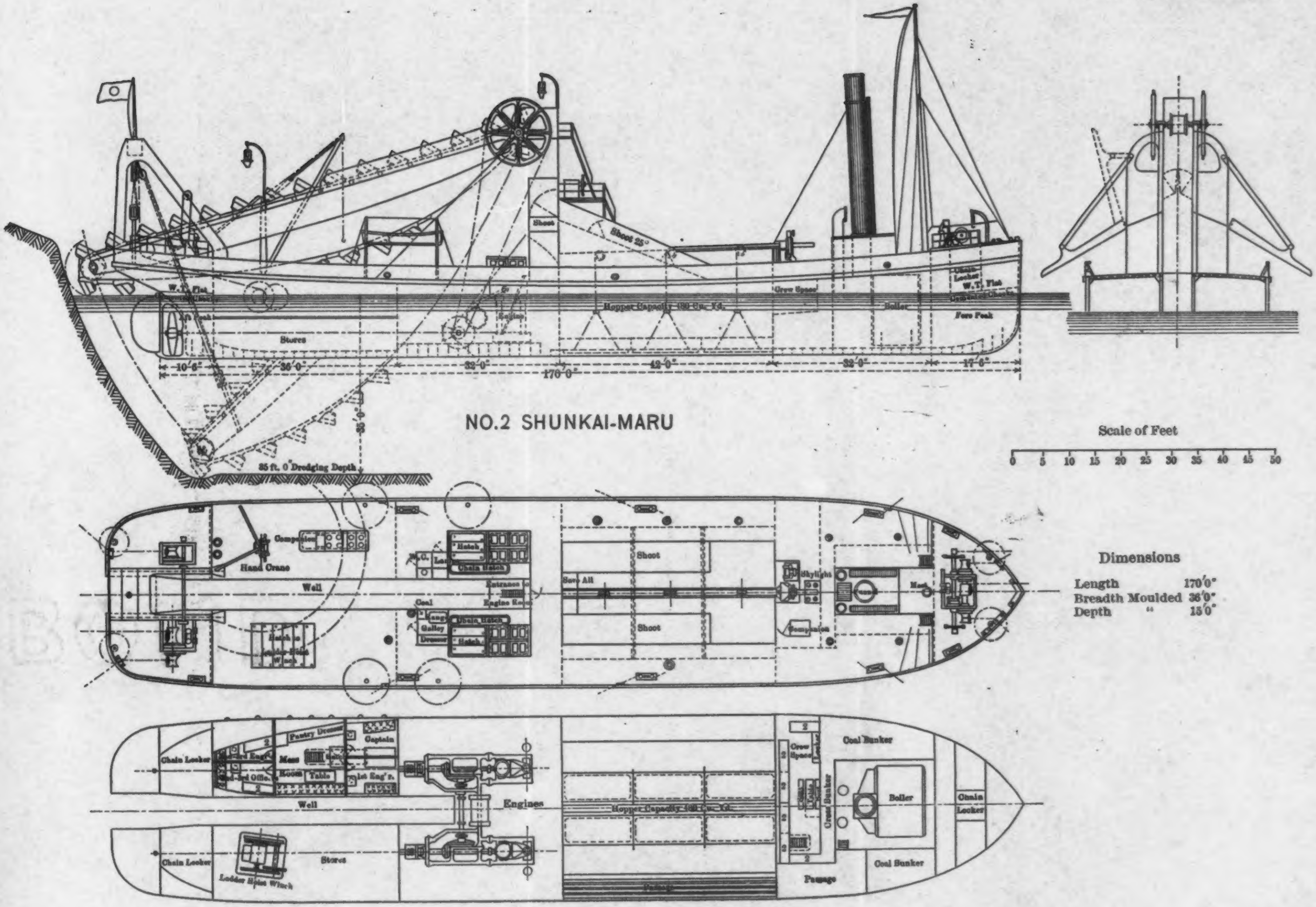
Pitch of chain $= (1 \text{ to } 1.2)\ \sqrt[3]{\text{bucket capacity}}$.

Width of chain $= (1.0 \text{ to } 0.55) \times$ pitch.

Diameter of pin, in inches =

$$(0.6 \text{ to } 0.8)\ \sqrt{\text{bucket capacity in cubic feet}}.$$

PLATE XXXV. VOL. LIV. PART C.
TRANS. AM. SOC. CIV. ENGRS.
INTER. ENG. CONG., 1904.
KOBAYASHI ON
CRANE AND LADDER DREDGES.



NO.2 SHUNKAI-MARU

Scale of Feet

0 5 10 15 20 25 30 35 40 45 50

Dimensions

Length	170'0"
Breadth Moulded	36'0"
Depth "	13'0"

Bucket.—The bucket should be such that it can easily excavate the material without deformation, fill itself and discharge the contents into the shoots. It should also contain a quantity of water, just sufficient to clear the contents from the shoots. In capacity the bucket may be from 3 to 35 cu. ft., according to circumstances.

The buckets were formerly made of wrought iron, either welded solid or with riveted plates. The double links were of forged iron or of malleable cast steel, being riveted to the back; but with the continual jarring in working, the rivets soon became loose, then the holes began to wear. If taken off, they could be refastened with larger rivets, and so made to serve a little longer, but new backs had to be put on soon afterward. These repairs, being smithwork, were very expensive, and renewals had to be effected every half year. Now the buckets are generally made of cast steel, the back and the bottom, together with the double links, being in one piece, with flanges at the sides and bottom for receiving the front. The front piece is usually of steel plate, reinforced with a renewable cutting piece of special steel, or armed with tines when the soil is hard. Claws are sometimes used between the buckets for loosening hard clay and conglomerate.

The surface adhesion of the bucket varies with the square of the pitch of the bucket chain, while the contents vary with the cube; so that the larger the capacity of the bucket, the smaller will be the ratio of the adhesion to the contents. Again, to make the discharge easy, the longitudinal section of the bucket, both vertically and horizontally, is tapered.

In the old form of bucket many small holes were punched around the sides to drain out the water; but recently these have all been abandoned except one in the center of the front of the bucket, which is used only for transportation. Each pinhole of the double link should be bushed and a recess cast to prevent the pin from turning.

Link.—The link should have a large bearing surface, especially at the pinhole, and the pinhole should be bushed with a ring of hard steel. There are two kinds of links: the single link, used for the connection of two consecutive buckets; and the double link, which is fixed to the back plate of the bucket, and the end of which is connected to the single link by a pin. The double link of a large dredge is now generally cast in one piece with the back of the bucket. But

in a smaller dredge it is sometimes made of cast steel, or, rarely, built of steel bars, as in the dredges of the Atsuta Harbour Works, where the connecting link consists of two separate bars.

To economize material, a smaller section is sometimes given to the body of the single link than that around the pinhole, as may be seen in Figs. 9, 10 and 11.

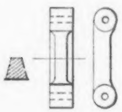


FIG. 9.

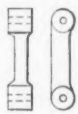


FIG. 10.

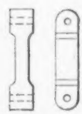


FIG. 11.

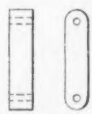


FIG. 12.

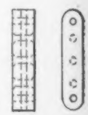


FIG. 13.

But, as the lower side of the link strikes against the face of the upper tumbler, these sections will not answer well in the long run. The two former do not permit the link to be reversed, which is necessary when wear sets in. The form shown in Figs. 12 and 13, though clumsy in appearance, will be better for such rough work as dredging. For a smal dredge the form shown in Fig. 12 is used, and for a large one the link is built up with three or more plates welded and riveted, as shown in Fig. 13.

There is another kind of link called the "hunting link," which is used to adjust the length of the bucket chain. This link serves to connect a bucket and an ordinary link, so as to lessen one pitch in the chain, and also to prevent the uneven wearing of the tumbler, caused by the buckets, coming on the same face.

The hunting link, however, reduces the dredging capacity, and is used only on a large dredge, where other convenient means of adjusting the bucket chain cannot be adopted. Suppose there are 30 buckets and a hunting link in the chain, then the loss of material dredged will be $\frac{1}{31}$ of the original capacity if the hunting link were not used. For this reason, the lower tumbler, or the upper end of the ladder of some small dredges, such as the *Asanagi* and *Yunagi* of the Osaka Harbour Works, is made to slide in a groove in order that the chain may be adjusted easily.

The usual proportions of height to thickness in single links is shown in Table 20.

TABLE 20.

Dredge.	Destination.	Bucket capacity. Cubic feet.	Height of link. Inches.	Width of link. Inches.
No. V and *No. VI*	Yodogawa.	4	$2\frac{3}{4}$	$1\frac{3}{8}$
Asanagi and *Yunagi*	Osaka.	6.5	$4\frac{5}{16}$	2
Koroku and *Ichimatsu*	Atsuta.	15.0	6	2 to $1\frac{1}{8}$
Zuiho	Keelun.	....	7	4 at end, $2\frac{1}{2}$ at middle.
Shinchiku	"	12	$7\frac{3}{4}$	$5\frac{5}{8}$
Shunkai No. 1	Osaka.	17	$6\frac{3}{4}$	$4\frac{1}{4}$ at end, $2\frac{3}{4}$ at middle
Shunkai No. 2	"	21	7	$2\frac{1}{2}$
Vladivostock	Vladivostock.	22	$7\frac{8}{16}$	$3\frac{9}{16}$

Thus,

Height, in inches $= (1.4 \text{ to } 1.7) \sqrt{\text{bucket capacity, in cubic feet.}}$

Thickness, in inches $= (0.4 \text{ to } 0.7) \times$ height.

On a small dredge sometimes the double link is not protected with bushes; but the contact surface is liable to be crushed, as is the case with the single link. The bush is a ring, $\frac{5}{32}$ to $\frac{7}{16}$ in. thick, made of a hard steel. It is desirable to prevent the bush from turning in the hole.

Pin.—The head of the pin is generally square or rectangular and fits into a groove of the same form in the double link, which prevents the pin from turning. Theoretically speaking, the form of the pinhead should correspond with the form of the upper tumbler, so as to allow the pin to be used with the same number of turns as the pinhead has sides, when wear sets in. In practice, however, it is better to turn the pin twice for a square tumbler, and perhaps three times for a pentagonal one, to make the wear around the surface equal. The other end of the pin is furnished with a split-pin or a split cotter. Washers are sometimes used to keep the pinhead firmly in the recess, and also to prevent bushes from getting out.

Formerly the pin was made of scrap-iron, case-hardened, or of mild steel, hardened, but the life of such a pin was quite short. Since the introduction of manganese steel the life of a pin has been made considerably longer.

The great delay and expense incident to the wear of the pins and links is still one of the disadvantages of the ladder dredge. To obviate this, there is Robinson's patent improved protected and lubricated joint connection. The pin is of unusually large diameter, and has a large and wide bearing, the whole width of the rear end

of the bucket, the pin being held fast in the narrow bearings at the front end. A removable bush of manganese steel is used, which, together with the use of a self-expanding packing ring and proper provision for lubrication, constitutes the most perfect and durable construction.

Tumblers.—The upper tumbler should transmit the driving power to the bucket chain smoothly and discharge the contents of the bucket upon the shoots instantly, so as to clear the bucket and the shoots.

For the first purpose it is necessary to make the polygon of the tumbler as nearly circular as possible.

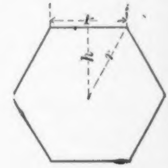


FIG. 14.

Now, in Fig. 14,

p = pitch = side of polygon,
n = number of sides of tumbler,
r = radius of describe circle,
h = distance of the side from the center.

$$h = \frac{1}{2} p \cot. \frac{\pi}{n} \quad r = \frac{1}{2} p \operatorname{cosec.} \frac{\pi}{n}.$$

The change of lengths, h and r, causes a corresponding change of moments in driving the chain. Again, the time required for a bucket, after touching the tumbler, to come to a vertically downward position will be

$$T, \text{ in minutes} = \left(\frac{\pi}{2} + \theta\right) = \frac{4\,k\,\pi}{n} = \frac{n\left(\frac{\pi}{2} + \theta\right)}{4\,k\,\pi},$$

where

k = number of buckets traversed per minute (assume = 16),

θ = angle of the driving chain to a horizontal line, say $= \frac{\pi}{\phi}$; or,

$$T, \text{ in seconds} = \frac{60 \times n \times \left(\frac{\pi}{2} + \frac{\pi}{4}\right)}{4 \times 16 \times \pi} = 0.703 \times n.$$

From Table 21 it will be seen that the smaller the number of sides of the tumbler the swifter will be the discharge, while the greater the number of sides the smoother the driving of the tumbler and the less the deflection. With small deflection, however, there will be danger of the tumbler's slipping. So the best results seem to be obtained with a five-sided or a four-sided tumbler. Generally,

a square form is adopted for the common dredge; but there are many dredges with five-sided tumblers.

TABLE 21.

Number of sides of tumbler.	T, in seconds.	Deflection of the consecutive sides.	r.	h.	$\frac{r}{h}$, or, ratio of moments of force.
3.	2.1	$\frac{2}{3}\pi$	0.58 p.	0.29 p.	2.00
4.	2.8	$\frac{1}{2}\pi$	0.71 p.	0.50 p.	1.41
5.	3.5	$\frac{2}{5}\pi$	0.85 p.	0.69 p.	1.24
6.	4.2	$\frac{1}{3}\pi$	1.00 p.	0.87 p.	1.15
7.	4.9	$\frac{2}{7}\pi$	1.15 p.	1.04 p.	1.11

The function of the lower tumbler is to guide the buckets for excavating soil, and not to transmit power. It is, therefore, necessary to give a smooth velocity to the mouthpiece of the bucket, so as not to cause a severe strain on the bucket.

Now, the angular velocity of the tumbler,

$$W \text{ per second} = 2\,k\,\frac{2\,\pi}{n} \times \frac{1}{60},$$

where k = number of buckets per minute,

n = number of sides of tumbler.

Suppose

$$k = 16 \text{ and } R = h + 1.2\,p$$

The linear velocity of the cutting edge of the bucket

$$V = R\,w = R\,\frac{4 \times 16 \times \pi}{n \times 60}.$$

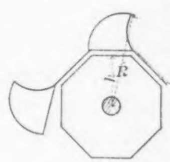


FIG. 15.

TABLE 22.

Number of sides of polygon.	Radius of inscribed circle.	R.	V per second, in terms of pitch.
3.	0.29 p.	1.49 p.	1.66 p.
4.	0.50 "	1.70 "	1.42 "
5.	0.69 "	1.89 "	1.27 "
6.	0.87 "	2.07 "	1.16 "
7.	1.04 "	2.24 "	1.07 "

Hence, the greater the number of sides, the slower will be the excavating velocity, and the greater will be the diameter of the

tumbler. When the tumbler is of great diameter, it will cause some obstruction to the side cutting of the dredge. In practice, the lower tumbler is made hexagonal when the upper one is five-sided, and pentagonal when the upper one is four-sided.

It must be noted that the soil is excavated by the bucket mainly when it rides on and is guided by the lower tumbler, and that otherwise the pins undergo severe shocks, and the rivets of the bucket soon work loose. Taking this into consideration, the buckets will work more effectively if we augment the number of sides of the tumbler, and thus increase the contact surface of the bucket with the soil. Although a large number of sides for a tumbler will cause some obstruction to the side cutting, yet the writer is of the opinion that better work may be done by giving the lower tumbler five sides for a soft material, and six sides for a stiff material which does not allow a deep cutting.

The top tumbler has to be made very strong, as it has to withstand great wear and tear. It is now commonly made of cast steel or, sometimes, of chilled cast iron. As the corner of the tumbler suffers the greatest wear, some old cast-iron tumblers are furnished with renewable corner-pieces of hard steel dovetailed into the body, or the faces are covered with steel plates firmly riveted. The top tumbler of some small dredges is made in two parts, but this is liable to become loose.

The lower tumbler is of cast steel, in one piece, having very deep and strong flanges. Some small dredges have cast-iron tumblers. The tumbler is fitted with a cast-iron bush, the full width of the tumbler, and revolves loosely on a wrought-iron shaft fitted to the ladder eyes by cross-dovetailed keys; or it is made to run in brackets at the lower end of the ladder, the axle being furnished with cast-iron bushes. The flanges are bevelled to suit the form of the buckets, the play being about 2 in. It is desirable that the bearings of the bottom tumbler be so arranged that they can be readily renewed without disconnecting the bucket chain. There are some arrangements for lubricating the lower tumbler, but they are not used.

There is another tumbler, sometimes found on French dredges, as on the *Pas-de-Calais,* and the dredge for Charente. It is used behind the following or suspended portion of the bucket chain, to

deflect it, and may be called the intermediate tumbler. This is claimed to have the following advantages:

First.—It gives the buckets a better direction for attacking the soil;

Second.—It increases the dredging depth, and

Third.—It makes thorough discharge of the contents of buckets with a small inclination of the ladder. This tumbler, however, causes a great shock to the bucket chain. The tumbler, after being struck by a bucket, takes a revolving motion, which increases the intensity of the following shock. But this shock can be somewhat lessened by using a brake.

Ladder.—The lower tumbler is attached to the free end of the ladder, the other end of which is hinged to the bridge a little below the upper tumbler, and which is suspended by chains or a wire rope, so that the free end may be adjusted to any depth required. There are two methods of mounting the tumbler, one is fixed and the other is movable. The latter method, which is used only for a smaller dredge, affords very convenient means for adjusting the slack of the bucket chain. The shaft supporting the upper end of the ladder is placed about 6 ft. below the upper tumbler shaft measured in the direction of 45 degrees. As the ladder is apt to be exposed to severe shocks, some French dredges are fitted with buffer springs at the upper end of the ladder, to lessen the shock and allow the shaft bearing to slide in a groove when extra resistance is met.

The bucket chain, like a belt, is liable to cause the upper tumbler to slip without driving the chain if it be too slack for the distance apart of the tumblers. The writer found that the maximum slack of the chain, measured, normally, from the link center of the upper chain to that of the lower, when the ladder is lifted, would best be $\frac{1}{6}$ of the tumbler distance for a hard soil, and $\frac{1}{5}$ or, rather, $\frac{2}{11}$ for a soft material.

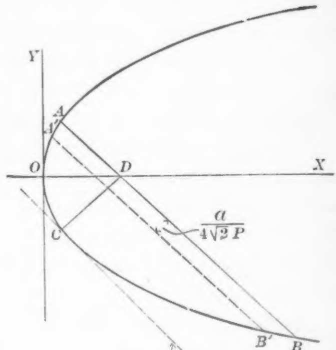
The bucket chain, when suspended, will take the form of a catenary. But suppose it to be a parabola represented by $A\ O\ C\ B$ in Fig. 16.

$$u = y - \sqrt{p}\, x^{\frac{1}{2}} = 0,$$

$O\ Y$ and $O\ X$ are the co-ordinate axes.

Now, in order to prevent the chain from overriding the tumbler at A, it is necessary, at least, that the ladder, $A\ B$, when it is at the

maximum inclination of 45°, will be normal to the curve at the point, A, or will make an angle of less than 90° with the bucket chain, $A\ O\ C\ B$, at the point, A.



Parallel to $A\ B$ and tangential to the curve

FIG. 16.

If the ladder is normal to the chain, the following relations must be fulfilled:

$$\frac{d\,u}{d\,y} = -1\,\frac{d\,u}{d\,x},$$

$$y = \sqrt{P}\,x^{\frac{1}{2}},$$

whence $x = \frac{1}{4}P$ and $y = \frac{1}{2}P$, which are co-ordinates of A.

Next, the co-ordinates of B will be

$$y - \frac{1}{2}P + \left(x - \frac{1}{4}\right) = 0,$$

$$y - \sqrt{P}\,x^{\frac{1}{2}} = 0,$$

$$y = -\frac{3}{2}P \text{ and } x = \frac{9}{4}P.$$

Again, the co-ordinates of the contact point, C, of the tangent line which is parallel to $A\ B$, are

$$\frac{d\,u}{d\,x} + \frac{d\,u}{d\,y} = 0,$$

$$y - \sqrt{P\,x}^{\frac{1}{2}} = 0,$$

$$x = \frac{1}{4}P \text{ and } y = -\frac{1}{2}P.$$

Hence, the normal at C will pass through the intersection of $A\ B$ and $O\ D$.

$$\text{Length, } C\ D = \frac{1}{\sqrt{2}}P \text{ and } A\ B = \sqrt{8}\ P.$$

The ratio of the slack of the chain to the distance of the tumblers is $\frac{1}{4}$.

Again, treating of another, $A\ B$, which makes an angle of less than 90° with the curve, or, reducing the length, $C\ D$, by $\frac{a}{4\sqrt{2}}P$,

where a is some constant, the length of $A'B'$ will be $P\sqrt{2\,(4-a)}$.

$$\text{So the ratio} = \frac{\sqrt{4-a}}{8}.$$

Hence, $\frac{1}{4}$ is found to be the allowable maximum limit, when the ladder is at its maximum inclination, that is, 45 degrees.

But the same length of chain will have another relation, if the ladder, $A\ B$, is kept horizontal.

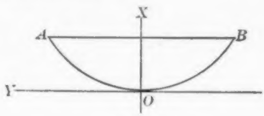


FIG. 17.

$$A\ B = \sqrt{8\,P}.$$

$$\text{Curve } A\ O\ B = \left[\frac{y\sqrt{y^2 + \left(\frac{P}{2}\right)^2}}{P} + \frac{P}{4}\log. \left(\frac{y + \sqrt{y^2 + \left(\frac{P}{2}\right)^2}}{\frac{P}{2}} \right) \right]_0^{\frac{P}{2}}$$

$$+ \left[\frac{y\sqrt{y^2 + \left(\frac{P}{2}\right)^2}}{P} + \frac{P}{4}\log. \left(\frac{y + \sqrt{y^2 + \left(\frac{P}{2}\right)^2}}{\frac{P}{2}} \right) \right]_0^{\frac{3}{2}P}$$

$$= 3.4006\,P.$$

Then the new parabola, $y^2 = P'\,x$, where

$$2\left[\frac{y\sqrt{P^2 + \left(\frac{P'}{2}\right)^2}}{P'} + \frac{P'}{4}\log. \left(\frac{y + \sqrt{y^2 + \left(\frac{P'}{2}\right)^2}}{\frac{P'}{2}} \right) \right]_0^{\sqrt{2\,P}} = 3.4006\,P.$$

By solving the equations, we get $P' = 1.625 \times \sqrt{2P}$, whence

$$\frac{2y}{x} = \frac{2 \times 1.625 \times \sqrt{2P}}{\sqrt{2P}} = 3.25.$$

Thus the ratio will be 3.25 when the ladder is horizontal.

But in practice, the ratio $\frac{1}{5}$ to $\frac{1}{6}$, measured when the ladder is lifted, has been taken by the writer for the dredge of the Osaka Harbour Works. The larger the ratio, the more will be the initial tension of the chain, while a smaller ratio will not be permissible, as the chain is apt to override the lower tumbler. In general, however, a greater ratio is adaptable for hard soil, and a smaller ratio for soft mud.

The ladder must not be inclined too much. The maximum work is said to correspond to an inclination of 45°, and to diminish greatly when the inclination gets beyond 60°. Sometimes the ladder is constructed in two parts, so that the lower part may always have an inclination of 45 degrees.

The length should be such that the dredge may reach the maximum depth with a ladder at a maximum inclination of 45°, and discharge the spoil easily into the hopper or barge.

Some old dredges are so constructed as to have the ladder at the side of the hull. With this arrangement, the dredge may have two ladders, and can dredge close to the foot of quay walls at a great depth. Some authorities have claimed that dredges with two side ladders can do more work than those with a central ladder, being able to work with one ladder while the other is being repaired; and may afford easy access to the ladders and the bucket chains.

But friction, wear and tear are greater with two ladders, and may outweigh these other advantages. Also the double ladders make the dredge wider, and are apt to be exposed to a great shock when used in an open sea, and to break away from the hull, when dredging toward the side where there is no guide for the ladder. Two bucket chains do not work equally well, the bottom not being of absolutely the same quality, nor of equal depth at both sides of the dredge. Moreover, the dredge, when it has loaded a barge with spoil, has to wait for another, because each bucket chain can discharge only on its own side.

To meet these inconveniences, it is customary for the modern dredge to have a central ladder, which allows it to have two or more barges lying along both sides of the hull, and it may load either barge without any interruption. There are two kinds of central ladder wells: the close-ended, having a ladder well in the middle of the hull; and the open-ended. The close-ended well is an old form, adopted when the open end was thought objectionable. It is now used only in a special case, where there is no shallower depth of bed to be dredged than the draft of the vessel. The open-ended well is now generally used, as it can cut its own flotation. The bow-well is used for a single-screw dredge, and the stern-well for a twin-screw; the latter can develop a greater speed, as the bow may have the regular moulded lines of a vessel, but its first cost is greater than that of the former.

"Traversing gear" or other similar devices have been used on some large dredges to enable them to clear the foot of walls at a great depth. But they have been dispensed with since the introduction of the open-ended well.

Horizontal and Vertical Rollers.—For the purpose of guiding and supporting the bucket chain, a series of cast-iron rollers, sometimes chilled, and having projecting checks, are fitted horizontally to the bucket ladder. Some dredges have two or more vertical cast-iron rollers, which only act as guides to the bucket, but which can be dispensed with if the horizontal ones have large flanges. Rollers and their bearings should be so arranged that they can be readily renewed without disconnecting the bucket chain. The usual pitch of the rollers is 2 to 3.5 times that of the bucket chain; however, a small proportion, such as 2 or 2.5, will give a smooth working.

The diameter of the roller varies from 6 to 12 in., according to the pitch and the capacity of the bucket. The spindles, forged of wrought iron and bushed with cast iron, work in renewable cast-iron bushes in their brackets, securely fixed to the ladder. A device which would keep the axle clear of mud and sand and lubricated with grease would be a great improvement.

The upper and lower one or two rollers are subjected to severe shocks due to the vibration of the chain. On this account, they should have larger axles than the common rollers, and their di-

ameter should be made so large as to follow the inclination of the chain and thereby to reduce the shock. The upper rollers are sometimes fitted with springs.

Ladder Well.—The ladder well must be proportioned to the length of the ladder. In the self-propelling bow-well dredge, the ladder, when raised, rests wholly in the well, while it projects one or two buckets beyond the hull in some stern-well dredges. There are often non-propelling dredges which have their ladders projecting three or more buckets beyond the vessel.

The well also serves as a guide to the ladder when the dredge is side-cutting. So suitable rubbing pieces formed of elmwood and strengthened with flat bars are to be fixed to the upper and lower flanges at both sides of the ladder, and the well-plating also has fenders of steel plates on each side. A breakwater is to be fitted to the after end of the well, if it be a bow-well, to throw the current of water under the bottom of the vessel when steaming ahead.

Main Framing.—The top of the main framing should have an ample height to insure the easy discharge of the spoil on the barges or into the hopper well. It should have ample strength and stiffness and be easily painted. All parts should be arranged so as to be easily and conveniently accessible by ladders and gratings, and made thoroughly tight, so that the dredgings cannot splash on the deck. When the material to be dredged is muddy, a canvas or sheet-iron cover should be placed over the upper tumbler, allowing the buckets to pass under it; otherwise the spoil will spread over the deck.

Hoisting Appliance.—The hoisting shears should be constructed of a height sufficient to permit the bottom tumbler to be raised about 2 ft. clear of the water. They are well trussed and so arranged as to meet the various working strains effectively, and are firmly secured to the deck plating and floors. The cross-beams are suitably arranged for receiving and carrying the tackle required for hoisting the ladder, and a suitable platform and ladder with a socket and mast complete are provided.

For hoisting, independent engines are commonly used on large dredges; but sometimes a countershaft is taken from the main en-

gine. The action of the latter is simpler and quicker than that obtained by starting a pair of steam cylinders, and it does not require the same care and attention; but it entails the constant running of a shaft which is only used occasionally. In either case it is advisable to control the lifting and lowering of the ladder by handles so arranged on deck that one man can operate them. Two sets of chains are sometimes used for suspending a small ladder; but a wire rope is preferable for smooth and easy management. The purchase gear consists of two blocks with from 3 to 5 sheaves. The upper sheave hangs from the forecastle, and the lower is fitted into a cross-head, which is to be connected to the straps at the lower end of the ladder by side rods. The wire rope is wound on a barrel with a helical groove, whose development is to be sufficient to take the whole length of the rope, without overriding, and 2 or 3 turns more.

The engine, usually having two cylinders, should have sufficient power to raise the lower tumbler at a rate of more than 6 ft. per min. Some gears are so constructed as to raise the ladder at two speeds, say, one of 7 ft. and the other of 13 ft. per min.

There is a pair of preventer wire ropes secured to the lower end of each side of the bucket ladder, which are to be used in case of accident to or failure in the working gear. They are lashed to forks cast on brackets for bucket-rollers. To release the main wire rope, when the dredge is not at work, two chains or rods hung from the forecastle, for suspending the ladder, or sometimes a wooden block is provided under the ladder and over the ladder well. A gauge for showing the depth of the buckets under water is to be marked on deck or on the side of the ladder well.

Methods of Discharging the Material.—There are many methods of discharging the material, which differ greatly from each other, according to the depth and the purpose of the discharge. The common method is to discharge into spoil wells in barges or on the vessel itself. This apparatus is called the self or barge-loading shoot. There is another kind of shoot, called the long shoot, which is used to discharge into an enclosed spot to be reclaimed. These shoots discharge material by gravitation. Other methods are used to transport the spoil mechanically: by transporting platform and by

floating pipes or a combination of floating and land pipes. The former is used to load wagons waiting on the bank, and the latter to deposit the material on shore.

The self or barge-loading shoot, or simply the shoot, is an inclined plane by which the dredged material is discharged by gravity into wells, either of barges or of the dredge itself. If it is for self loading, the shoot usually consists of two closed inclined channels, or, sometimes, of one channel for a dredge of small bucket capacity. Each channel has a certain number of hinged doors for distributing the spoil equally over the well. If it is for barge loading, the upper part of the shoot is fixed and closed, while the lower part, projecting overboard, is open and hinged, so that it may be raised or lowered. The barge-loading shoots are generally situated at both sides of the hull; but when it is necessary to dredge hard by a quay wall, or to work in a small canal where the transporting barge cannot lie alongside the dredge, the shoot is so constructed that the spoil may be discharged into the opposite side of the ladder.

The inclination of the shoot varies with the nature of the soil to be dredged. Wet clay will slide down a shoot inclined 1 in 5 to 1 in 3, if comparatively free from sand; but wet sand or gravel will not slide down an incline of even 1 in 2 without a free flow of water to aid it; otherwise it requires much pushing. So the shoot is sometimes supplied with water continuously from a service pump or a special auxiliary pump. The usual slope of the fixed part of the shoot is 25 to 35° or 1 in 1.5 to 1 in 2.2, but an inclination of from 1 in 1.8 to 1 in 2 is preferable. As to the hinged part, the slope is somewhat less than that specified: 1 in 2 to 1 in 5. It changes with the freeboard of barges to be loaded.

To give the shoot such an inclination, the upper tumbler should, naturally, be placed high. To obviate this, Messrs. Fleming and Ferguson designed a dredge having its top tumbler slightly above the deck, the remainder of the elevation being effected by a light elevator. Mr. Hunter has devised a screw placed in a trough a few feet above the deck, by which the dredged material may be led to any part of the vessel. But the advantage gained by not lifting so high is not more than counterbalanced by the extra friction and the extra wear and tear of these devices.

The usual shoot is 6 to 4 ft. in breadth, and 4 to 2 ft. in depth. The section is commonly rectangular, but the bottom is sometimes curved. The end of the shoot is often covered, having a curved trumpet mouth, so as to guide the material, when the spoil well is too small. This is what the writer used in the dredges of the Osaka Harbour Works, where the dredged material splashed over the deck of the hopper barge of 100 tons capacity.

The rocking plate at the top, which directs the dredged material to any shoot, is hinged on strong brackets having large surfaces properly fastened and worked from the deck with proper back balance weight. The plate is formed of two steel plates riveted to an iron frame, the space between the plates inside the frame being filled with timber and properly riveted, caulked and balanced. The turning of the rocking plate and the folding of the hinged shoots are generally accomplished by a hand winch, or by a steam steering winch, which the writer adopted in the dredge *Shunkai No. 2.* Some dredges have an independent engine for hoisting and lowering the shoots.

The long shoot should be well covered in to prevent splashing on the deck. The shoot is conical or circular in section. Its dimensions vary with the capacity of the dredge, but the usual diameter is 1½ to 3 ft., widened in the highest point to 1.8 times, nearly. It is made slightly conical by enlarging the diameter 8 in. or more at the delivering extremity, so that it will not choke with large materials. Sometimes a closed conduit is used. The advantage of this is that with a jet of water the material can be pushed out with much force.

The slope of the long shoot is entirely dependent upon the nature of the material to be discharged. The inclination, together with the height of the point of discharge above water, determines the height of the top tumbler. According to Mr. Webster, the following are found from experience to be the best angles for different kinds of soil: for soft mud, 1 in 10; for soft clay, 1 in 12 to 14; for hard clay, 1 in 14 to 16; and for fine sand and water, 1 in 20 to 25. Moreover, from experiments made in the Suez Canal, it was found that fine sand, mixed with an equal quantity of water, would flow down a slope of 1 in 25; but with a flatter slope, no matter how much water was used, the sand would separate from the water and form a

hard cake on the bottom of the shoot. The usual inclination adopted is 1 in 10 for the upper part and 1 in 20 for the lower part. The dredged material tumbles on a conduit placed about 6 ft. lower than the tumbler, where it is mixed with water pumped out. An appropriate proportion of water seems to be 2 to 3 times the solid matter in volume. It is necessary to supply a grating at the beginning of the conduit so as not to admit hard masses or large pieces of material before they are mixed with water.

The shoot is supported by wire ropes fastened to the head of a sheerlegs, which is mounted on the dredge, or on a special pontoon rigidly connected to the hull of the dredge. The back-guys of the sheers are connected to a pontoon which lies on the opposite side of the dredge and has a pump and an engine for providing water ballast.

The transporting platform or conveyor which has been generally used, consists of beams guiding and supporting an endless band composed of steel plates connected by pins. The dredge discharges material upon this band, which is driven by a special independent steam engine. The platform is used for discharging the dredged material directly ashore wherever the banks are low and within reach. It can transport material to a distance of more than 1 000 ft., and also to a height greater than that of the dredge. It is specially suited for a dry and firm soil, which is intended to be transported by wagons. Though excellent, this apparatus is liable to stop the dredging, for it has to wait for wagons to charge. The dredging quantity is, therefore, said to be reduced to $\frac{6}{7}$ that of a barge-loading dredge of similar construction and of equal capacity.

The rubber belt conveyor, by which muddy or even liquid material can be transported, has been introduced recently. The apparatus is formed of a steel frame carrying a great number of rollers, formed of steel tubes. On these rollers runs a heavy rubber belt, made especially for the purpose, and the rollers are carried in improved dirt-protected, balanced bearings. A small belt, about 120 ft. long, can be supported entirely from the dredge. Some conveyors are so constructed that they can revolve and thus be used on either side of the dredge.

Floating pipes, or a combination of floating and land pipes, are used for discharging the dredged material into the sea or on shore,

by pumping. The material raised by the buckets is discharged directly from the upper tumbler into a reservoir containing bar-screens for breaking up the material and preventing large stones or boulders from entering the pipe. An independent centrifugal pump delivers a large volume of water through a series of jets, pulverizing and breaking up the material, which can then be dealt with by the discharge pump. Water is also introduced by an inlet from the sea to the bottom of the reservoir and opposite the inlet to the discharging pump. The discharge pipes are led over the deck and connected to the floating pipe line by a flexible joint. The floating pipes are supported by floaters, and connected with flexible joints to allow a free motion to the dredge and to each floater. When the dredged spoil is to be discharged into the sea, the end of the discharge pipe should be moved so as to distribute the spoil over the site. This motion can be obtained by chains and anchors, a hydraulic deviator or propellers. But when the spoil is to be delivered on shore, the floating pipe line is connected to land pipes laid upon the beach or supported on a trestle. The length of such pipes is commonly from 1 000 to 2 000 ft., but may be increased to 6 000 ft. The writer will not enter into the details of such mechanisms, as they belong properly to the pump dredge.

Hopper and Hopper Door Winches.—The self-loading dredge usually has a bottom hopper well. The well is rectangular in plan, and in the longitudinal section; but in the transverse section it sometimes tapers toward the bottom. This is to make the door small so as to be easily manageable. It frequently occurs that the spoil does not get out. On this account the sides of the well are generally made nearly vertical. The doors are usually built of iron plates with wooden lining in two thicknesses, stiffened around the edge with angles. Each door has two or three stout iron hinges and two eye bolts to be hung on two chains. The two chains are attached to a balance, which is suspended to a chain passing through a pulley. This chain has a wedge holder; a wedge with hardened faces bears on a proper chock for sustaining the load on the door chains during the operations of loading and transporting. All chains above the wedges are connected to an iron bar worked by steam or hydraulic power. Sometimes the doors are actuated by a steam screw gear, so arranged that they need be only partly opened,

when desired, which allows the spoil to be discharged in shallow water.

Mooring Means.—Anchor spuds are rarely used on some non-propelling dredges working in a narrow canal. But for working in an open place, where there is abundance of room to move the dredge from side to side, the spuds are dispensed with and anchors are generally resorted to.

Maneuvering Winches.—For a long time, there has been used on the middle of the deck, a simple but strong windlass, around which the mooring chains wind. But this is inconvenient since, in case of damage, the swinging motion cannot be continued. On the contrary, the use of two separate winches, one on the stern, and one on the bow, has the advantage that the dredging can be proceeded with even when one of the winches gets out of order. Of course, the former needs less labour; but, a certain number of the crew being necessary on deck for other work may also be used for watching the winches. Moreover, several separate winches, being able to treat a great number of chains at the same time with different speeds, are thought to be advantageous.

Formerly there were many dredges which had their winches driven by the main engine. Some authorities were of the opinion that it was preferable for the head and tail chains to be worked by separate engines; but the quarter chains were best connected with the main engine. On a perfectly level bottom, with soil of uniform quality, the action of the winches, for side chains, will coincide with the buckets; and, as there is a close relation between the two operations, these winches are more economically worked by the main engine, both as regards power and attendance. The tail winch, from which the chain is paid out on the brake during the operation of dredging, and which is driven rapidly in taking in the tail chain, is advantageously worked by separate steam cylinders. However, as a perfectly level bottom never exists in harbours, docks or rivers, the motion of the buckets and chains must vary considerably, and should be independent in their action; separate winches being advisable, not only to meet this irregularity, but also for manipulating the vessel when not dredging. Yet the writer is of the opinion that in a small non-propelling dredge all movements should be effected by the main engine, using friction clutches, arranged so

that it will be possible to put each mechanism in or out of gear independently, or to go ahead or astern, reversing gear being provided.

Anchors and Chains.—Six anchors and six chains are used for dredging. The head anchor is usually larger than the tail anchor, except in a stern-well dredge, which has two similar anchors. The other anchors are smaller than these, being used only for quarter mooring. The chains, all of short links, should be of lengths to suit the widths of the channel to be dredged, respectively. The two fore chains have commonly a greater diameter than the aft. All chains should be provided with swivels to release the torsional force. Short pitch shackles are to be provided for each set of chains, to connect them quickly when broken. For wide cutting, the front chain should be kept afloat by means of buoys or a boat with a water-tight deck, so as to allow the dredge to describe a great arc. When the chain is small and the site is sheltered, a boat is convenient; otherwise buoys are thought better.

Performance.

In the Osaka Harbour Works, four bucket ladder dredges are used for dredging. Two of the dredges, *Asanagi* and *Yunagi*, are non-propelling barge-loading dredges, each with a capacity of 200 tons per hour, and able to cut its own flotation. Their maximum dredging depth was 15 ft., which the writer increased to 22 ft. by lengthening the ladder and augmenting the chain with four buckets. All movements of the dredge are actuated by the engine, by means of friction-clutches, which make it possible to put each mechanism in or out of gear, the shoots only being raised by hand winches. The movement of the bucket chain and the upper tumbler are effected by belt and wheel gearing fitted with a hydraulic clutch. The shaft of the lower tumbler is so constructed as to be able to move 4 in. in a groove at the end of the ladder. The dredging site was open to the sea, so that the dredges were obliged to be towed into refuge during a swell of more than 2 ft. in height. The bottom was usually 0 to 6 ft. deep below low water, and was to be dredged formerly to 9 ft. below low water and to 15 ft. after the modification of the dredge. The upper 2 or 3 ft. of the bed was fine sand, which was very difficult to dredge, next 8 to 10 ft. of mud, and then blue soft clay. The

dredged spoil was charged into hopper barges of 100 tons capacity; and four barges were usually served to each dredge. A steam tugboat was used for both dredges when the discharging spot was within 1 600 yd. from the dredges.

The other two dredges, *Shunkai No. 1* and *No. 2,* are hopper dredges of 600 tons capacity, able to cut their own flotation. Their maximum dredging depth is 35 ft. *Shunkai No. 1* is of the bow-well type, while *No. 2* is of the stern-well type. Each has two steam winches for mooring chains, one at the bow and the other at the stern. It has also a steam winch for hoisting the ladder, and a dynamo for electric lamps. The bucket chain is driven by shafting in Dredge *No. 1* and by two sets of pitch chains in Dredge *No. 2.* The dredges were used where the depth changed from 6 to 28 ft., to dredge to their maximum depth. They were worked whenever the waves did not exceed 2½ ft. in height; though the dredges can work in a swell greater than that, but the barges, all being of 100 tons capacity, are not large enough to resist the wave action. The nature of the bed was fine sand, 2 to 3 ft. in thickness, where the original depth was 6 to 12 ft., and mud where the bed was deeper. At 20 to 24 ft. below low water there was found a soft blue clay. The spoil was usually charged into hopper barges; but before sunrise, and after sunset, or when waves were too high to use the barge, the spoil was loaded into the hopper of the dredge. Eight to ten barges were used for each dredge. A steam tugboat was used for each dredge when the transporting distance was not great; but three tugs were often used for both dredges when the depositing site was distant 1 200 yd. or more.

Cost of Transportation.—As may be seen in Table 26, some of the dredged material is transported by the dredges themselves. Thus, 2 152 hours 35 min. are spent for the transportation. If we suppose the average rate of expense is paid for the whole number of working hours, the cost of transportation will be 27.8 sen per tsubo, or 1.7 cents per cu. yd., and the true dredging cost will become 53.3 sen per tsubo, or 3.33 cents per cu. yd.

The transporting distance is from 400 to 2 000 yd. Usually, the dredged material is conveyed by tugs and hopper barges.

TABLE 23—PERFORMANCE OF THE STATIONARY DREDGES, *Asanagi* AND *Yunagi*, COMBINED.

Fiscal year.	Number of days.	Number of working hours.	Time Lost, Due to									Total.	Dredging hours.	Ten Tsubo Barge-Loading.		Small Barge-Loading.		Total quantity dredged. Tsubo.	Average dredged quantity per working hour. Tsubo.	Average quantity per dredging hour. Tsubo.
			Steaming.	Going to the site.	Shifting moorings.	Weather.	Repairs.	Going to the refuge.	Waiting for barge.	Cleaning.	Other causes.			Number.	Quantity. Tsubo.	Number.	Quantity, Tsubo.			
		h. m.	h. m.	h.m.	h. m.	h. m.	h. m.	h.m.	h. m.	h. m.	h. m.	h. m.	h. m.							
1898.....	173	1 916 00	312 00	3 30	114 20	13 50	54 40	.....	217 20	201 30	8 40	925 50	990 10	223	2 230.0	3 478	6 738.25	8 968.25	4.68	9.06
1899.....	704	8 110 50	826 20	21 00	317 50	543 50	2 138 00	5 10	275 45	414 50	88 20	4 631 05	3 479 45	3 902	39 020.0	1 835	3 861.50	42 881.50	5.29	12.32
1900.....	702	8 863 40	908 00	.....	250 15	607 05	2 579 35	.....	.....	570 47	511 43	5 427 25	3 436 15	5 264	52 640.0	.....	....	52 640.0	5.57	15.32
1901.....	704	9 192 20	1 093 30	.....	307 25	743 05	2 015 55	.....	2 40	597 25	411 25	5 171 25	4 020 55	6 624	66 240.0	160	320.0	66 560.0	7.24	16.55
1902.....	702	9 237 30	906 50	.....	164 00	694 15	1 485 50	.....	8 30	742 50	642 50	4 645 05	4 592 25	8 501	85 010.0	518	1 036.0	86 046.0	9.31	18.74
1903.....	706	9 126 00	1 073 20	.....	196 55	603 30	1 598 50	.....	26 10	758 25	240 10	4 497 20	4 628 40	9 839	98 390.0	67	180.0	98 570.0	10.80	21.30
Total...	3 691	46 446 20	5 120 00	24 30	1 350 45	3 205 35	9 872 50	5 10	530 25	3 285 47	1 903 08	25 298 10	21 148 10	34 353	343 530.0	6 058	12 135.75	355 665.75	7.66	16.82
Average per dredge per day.........		12 25	1 23	.....	0 22	0 52	2 41	0 00	0 09	0 53	0 31	6 51	5 44	......	93.07	.....	3.29	96.36	.....	......
Percentage...		100.00	11.02	0.05	2.91	6.91	21.26	0.01	1.14	7.07	4.10	54.47	45.53	......	....	.....	....	....	.....	......

1 tsubo = 8 cu. yd.
The amount is measured by barge, and is calculated to be $1\frac{1}{4}$ times place measurement.

TABLE 24.—RUNNING EXPENSES FOR *Asanagi* AND *Yunagi*, COMBINED.

Fiscal year.	Number of days.	LABOUR. Number of crew.	Salaries. Yen	Boarding. Yen.	Premium. Yen.	Total. Yen.	MATERIALS. Coal used. Pounds.	Cost of coal. Yen.	Oil, etc. Yen.	Other expenses. Yen.	Total. Yen.	Repairs. Yen.	Depreciation of 10 per cent. Yen.	Interest of 5 per cent. Yen.	Total. Yen.	Unit cost per tsubo. Sen.
1898....	327	2 576	1 397.105	....	....	1 397.105	217 000	787.692	300.176	446.431	1 534.299	1 155.644	7 646.407	3 823 203	15 556.658	173.5
1899....	730	5 737	2 628.200	634.100	....	3 262.300	589 250	2 163.100	814.843	1 117.971	4 095.914	5 691.845	15 292.813	7 646.407	35 989.279	83.9
1900....	730	6 582	3 044.330	827.360	1 398.906	5 270.596	590 000	2 020.090	962.707	952.286	3 935.083	10 090.079	15 292.813	7 646.407	42 234.978	80.2
1901....	730	6 531	3 017.397	805.670	655.545	4 478.612	705 200	2 916.598	720.734	668.548	4 305.880	10 904.284	15 292.813	7 646.407	42 627.996	64.0
1902....	730	6 604	2 977.680	820.240	2 029.942	5 827.862	700 000	2 206.550	504.317	261.255	2 972.122	9 331.380	15 292.813	7 646.407	41 070.584	47.7
1903....	732	6 658	2 971.678	824.640	2 472.481	6 268.799	795 800	1 932.295	618.665	279.305	2 830.265	9 287.028	15 292.813	7 646.407	41 325.312	41.9
Total..	3 979	34 688	16 036.390	3 912.010	6 556.874	26 505.274	3 597 250	12 026.325	3 921.442	3 725.796	19 673.563	46 460.260	84 110.472	42 055.238	218 804.807	61.5*
Average per dredge per day..		8.7	4.030	0.983	1.684	6.661	904	3.022	0.986	0.936	4.944	11.677	21.139	10.569	54.985	......
Percentage...		......	7.34	1.79	2.98	12.11	....	5.50	1.79	1.70	8.99	12.24	38.44	19.22	100.00	......

The fiscal year begins April 1st. The number of days in Table 23 does not include holidays and those during which the dredge was used for other purposes.

The dredge *Asanagi* commenced work Oct. 18th, and *Yunagi* Oct. 27th.

1 yen = 50 cents.

The cost of transportation is not included in Table 24.

* 61.5 sen per tsubo = 3.84 cents per cu. yd.

TABLE 25.—EXPENSES FOR HOPPER DREDGES *Shunkai No. 1* AND *No. 2*, COMBINED.

Fiscal year.	Number of days.	Labour.					Material.					Repairs. Yen.	Depreciation of 10 per cent. Yen.	Interest of 5 per cent. Yen.	Total. Yen.	Unit cost per tsubo. Sen.
		Number of crew.	Salary. Yen.	Boarding. Yen.	Premium. Yen.	Total. Yen.	Coal used. Pounds.	Cost of coal. Yen.	Oil, etc. Yen.	Other expenses. Yen.	Total. Yen.					
1900....	491	14 125	6 450.048	1 810.810	....	8 260.858	1 940 000	6 728.850	1 458.189	792.915	8 979.954	14 923.583	39 784.284	19 892.142	91 840.821	130.1
1901....	730	25 219	10 627.067	3 127.870	3 092.930	16 847.867	5 875 000	24 246.825	2 092.203	1 016.825	27 355.853	25 553.739	56 206.215	28 103.108	154 066 782	51.6
1902....	730	22 351	9 699.629	2 811.630	6 531.117	19 042.376	5 155 000	15 898.400	1 314.003	500.479	17 712.882	34 743.034	56 206.215	28 103.108	155 807.675	46.9
1903....	732	20 462	8 929.477	2 564.250	4 437.641	15 931.368	5 885 000	14 249.270	1 479.186	558.490	16 286.946	31 861.951	56 206.215	28 103.108	148 389.588	56.5
Total..	2 683	82 157	35 706.221	10 314.560	14 061.688	60 082.469	18 855 000	61 123.345	6 343.581	2 868.709	70 335.635	107 082.307	208 402.929	104 201.466	550 104.806	57.0*
Average per dredge per day........		30.6	13.308	3.845	5.241	22.394	7 028	22.782	2.364	1.069	26.215	39.911	77.675	38.838	205.033	......
Percentage..		....	6.49	1.88	2.55	10.92	....	11.11	1.16	0.52	12.79	19.47	37.88	18.94	100.00	......

The fiscal year begins April 1st. The number of days in Table 26 does not include holidays and those during which the dredges were used for other purposes.
Dredge No. 1 commenced work July 4th, and No. 2 August 17th, 1900.
1 yen = 50 cents.
Expenses due to tugs and barges are not included in Table 25.
*57 sen per tsubo = 3.56 cents per cu. yd.

Cost of the Plant.

5	Steam tugs, each of 33 tons....................	81 265.80 yen
26	Wooden hopper barges, each of 80 cu. yd.........	295 651.80 "
10	Steel hopper barges, each of 80 cu. yd............	160 000.00 "

In 1901 four of the wooden barges were converted into pontoons for floating cranes.

The running expense will be seen in Table 27.

Premium Rate.—A premium proportional to the dredged quantity was awarded to the crew. At first an appropriate monthly standard amount of work was assigned to each dredge, tug and barge, respectively. Then a premium was paid only for the quantity of work which was done after that standard had been reached. Afterward

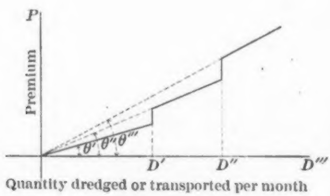


FIG. 18.

the premium was discontinued because the crew remained idle when the amount of work was sure not to reach the standard. The rate now used is directly proportional to the dredged amount, as

$$P = K\,D,$$

where P = premium,

D = quantity dredged or transported,

K = constant, varying with D.

Thus, $K = \tan.\ \Theta'$, when $D \not> D'$.

$= \tan.\ \Theta''$, when $D' < D \not> D''$.

$= \tan.\ \Theta'''$, when $D > D''$.

D' and D'' are certain limits.

Now, taking P in sen and D in tsubo, we have the following values of K respectively within specified limits of D' and D''.

TABLE 26.—Performance of the Hopper Dredges, *Shunkai No. 1* and *No. 2*, Combined.

Fiscal year.	Number of days.	Number of working hours.	Time Lost, Due to: Steaming.	Going to the site.	Shifting mooring.	Taking off and up mooring.	Weather.	Repairs.	Going to the refuge.	Transportation of spoil.	Coaling.	Waiting for barge.	Feeding water.	Cleaning.	Other causes.	Total.	Dredging hours.	Self-loading. Number.	Self-loading. Quantity. Tsubo.	Barge-loading. Number.	Barge-loading. Quantity. Tsubo.	Total quantity dredged. Tsubo.	Average quantity dredged per working hour. Tsubo.	Average quantity dredged per dredging hour. Tsubo.
		h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.							
1900	474	5 261 30	382 45	33 30	278 15	114 10	659 15	1 608 35	16 30	154 00	2 10	165 05	......	279 35	123 35	3 812 25	1 449 05	113	6 780	6 383	63 830	70 610	13.42	38.72
1901	704	9 398 35	750 40	48 40	321 05	37 40	733 25	1 841 50	6 55	743 05	6 30	98 15	4 30	326 35	21 00	4 940 10	4 458 25	695	41 640	25 722	257 080	298 720	31.80	67.03
1902	702	9 199 40	764 10	43 20	249 50	......	841 25	1 797 40	......	685 45	.....	63 00	......	229 40	11 30	4 686 20	4 513 20	822	50 490	28 192	281 920	332 410	36.13	73.65
1903	706	8 719 30	643 30	27 40	261 10	......	755 00	2 392 05	......	417 55	.....	72 30	......	231 55	263 50	5 065 35	3 653 55	527	31 590	23 104	231 040	262 630	30.12	71.88
Total.	2 586	32 579 15	2 541 05	153 10	1 105 20	151 50	2 989 05	7 640 10	23 25	2 000 45	8 40	398 50	4 30	1 067 45	419 55	18 504 30	14 074 45	2 157	130 500	83 401	833 870	964 370	29.60	68.52
Average per dredge per day.		12 36	0 59	0 04	0 26	0 03	1 09	2 57	0 01	0 46	.....	0 09	......	0 25	0 10	7 09	5 27	......	50.46	......	322.46	372.92	......	......
Percentage.		100.00	7.80	0.47	3.39	0.47	9.17	23.45	0.07	6.15	0.03	1.22	0.01	3.28	1.29	56.80	43.20	......	......	......	......	......	......	......

1 tsubo = 8 cu. yd.
The amount is measured by barge, and is calculated to be 1¼ times place measurement.

TABLE 27.—Cost of Transportation (Tugs and Hopper Barges).

Fiscal year.	Vessel.	Labour. Salary. Yen.	Labour. Boarding. Yen.	Labour. Premium. Yen.	Labour. Other expenses. Yen.	Labour. Total. Yen.	Materials. Coal. Quantity used. Pounds.	Materials. Coal. Cost. Yen.	Materials. Oil, etc. Yen.	Materials. Other expenses. Yen.	Materials. Total. Yen.	Repairs. Yen.	Depreciation of 10 per cent. Yen.	Interest of 5 per cent. Yen.	Total. Yen.	Quantity transported. Tsubo.	Unit cost, in sen per tsubo.
1899	Tug....	2 762.688	757.600	....	....	3 519.688	937 100	3 347.808	601.770	491.808	4 441.386	3 487.049	3 502.193	1 751.097	16 701.413		42.0
	Barge..	2 752.285	....	....	2 255.155	5 007.440	....	....	707.304	346.558	1 053.862	12 902.315	24 076.867	12 038.434	55 078.918		138.6
	Total...	5 514.373	757.600	....	2 255.155	8 527.128	937 100	3 347.808	1 309.074	838.366	5 495.248	16 389.364	27 579.060	13 789.531	71 780.331	39 731.0	180.6
1900	Tug....	5 577.681	1 695.740	1 371.746	....	8 645.167	2 366 400	7 947.750	1 299.071	886.412	10 133.233	5 944.717	5 864.080	2 932.040	33 519.237		28.4
	Barge..	9 736.077	....	561.830	2 149.665	12 447.572	....	....	1 327.624	572.917	1 900.541	21 781.844	45 565.180	22 782.590	104 477.727		88.6
	Total...	15 313.758	1 695.740	1 933.576	2 149.665	21 092.739	2 366 400	7 947.750	2 626.695	1 459.329	12 033.774	27 726.561	51 429.260	25 714.630	137 996.964	117 934.0	117.0
1901	Tug....	7 741.295	2 342.060	4 329.283	....	14 412.638	3 788 200	15 323.585	1 536.046	829.158	17 688.789	6 736.853	8 126.580	4 063.290	51 028.150		15.2
	Barge..	15 064.610	....	2 344.320	2 574.635	19 983.565	....	....	990.502	684.363	1 674.865	29 152.184	42 631.847	21 315.923	114 758.384		34.1
	Total...	22 805.905	2 342.060	6 673.170	2 574.635	34 396.203	3 788 200	15 323.585	2 526.548	1 513.521	19 363.654	35 889.037	50 758.427	25 379.213	165 786.534	336 127.0	49.3
1902	Tug....	7 807.030	2 353.690	4 993.170	....	15 153.890	3 822 200	11 860.583	956.098	513.459	13 330.140	11 068.615	8 126.580	4 063.290	51 742.515		13.7
	Barge..	15 007.690	....	8 526.380	1 767.080	25 301.150	....	....	805.068	778.250	1 583.318	21 499.656	41 165.180	20 582.590	110 131.894		29.2
	Total...	22 814.720	2 353.690	13 519.550	1 767.080	40 455.040	3 822 200	11 860.583	1 761.166	1 291.709	14 913.453	32 568.271	49 291.760	24 645.880	161 874.409	377 310.0	42.9
1903	Tug....	7 961.810	2 350.880	4 367.801	....	14 680.491	4 059 000	9 905.355	1 062.174	525.583	11 493.112	9 607.600	8 126.580	4 063.290	47 971.073		14.1
	Barge..	15 048.200	....	7 584.360	1 170.120	23 802.680	....	....	886.000	806.632	1 692.632	22 887.924	41 165.180	20 582.590	110 131.006		32.3
	Total...	23 010.010	2 350.880	11 952.161	1 170.120	38 483.171	4 059 000	9 905.355	1 948.174	1 332.215	13 185.744	32 495.524	49 291.760	24 645.880	158 102.079	341 195.0	46.4
Entire Total.	Tug....	31 849.904	9 499.970	15 062.000	....	56 411.874	14 972 900	48 385.081	5 455.159	3 246.420	57 086.660	36 844.834	33 746.013	16 873.007	200 962.385		16.6
	Barge..	57 608.862	....	19 016.890	9 916.655	86 542.407	....	....	4 716.498	3 188.720	7 905.218	108 223.923	194 604.254	97 302.127	494 577.929		40.8
	Total...	89 458.766	9 499.970	34 078.890	9 916.655	142 954.281	14 972 900	48 385.081	10 171.657	6 435.140	64 991.878	145 068.757	228 350.267	114 175.134	695 540.317	1 212 297.0	57.4*
Percentage......		12.86	1.37	4.90	1.42	20.55	....	6.96	1.46	0.92	9.34	20.86	32.83	16.42	100.00	....	......

The fiscal year begins April 1st. The figures in the column, "Other expenses," under "Labour," represent the wages of assistant workmen.
1 tsubo = 8 cu. yd. 1 yen = 50 cents. *57.4 sen per tsubo = 3.59 cents per cu. yd.

TABLE 28.—VALUE OF K.

Crew.	Priestman's Dredge.			200-Ton Dredge.			600-Ton Dredge.			Tug.			Barge.		
	$D \ngtr 400.$	$400 < D \ngtr 800.$	$D > 800.$	$D \ngtr 2\,000.$	$2\,000 < D \ngtr 4\,000.$	$D > 4\,000.$	$D \ngtr 10\,000.$	$10\,000 < D \ngtr 20\,000.$	$D > 20\,000.$	$D \ngtr 8\,000.$	$8\,000 < D \ngtr 16\,000.$	$D > 16\,000.$	$D \ngtr 800.$	$800 < D \ngtr 1\,600.$	$D > 1\,600.$
Captain	....	....	....	....	....	....	0.18	0.21	0.24	0.17	0.20	0.24	....	....	....
Engineer	2.2	2.7	3.1	0.78	0.94	1.09	0.22	0.26	0.30	0.17	0.20	0.24	....	....	....
Mate and second	....	....	....	....	....	....	0.11	0.13	0.15	....	....	....	....	....	....
Boatswain and chief fireman	....	....	....	....	....	....	0.07	0.08	0.09	....	....	....	....	....	....
Steersman and oiler	0.8	0.9	1.1	0.16	0.19	0.22	0.04	0.05	0.06	0.07	0.08	0.10	....	....	....
Sailor, fireman and cook	0.8	0.9	1.1	0.12	0.15	0.18	0.04	0.04	0.05	0.05	0.06	0.07	....	....	....
Boy	....	....	....	....	....	....	0.02	0.02	0.02	0.03	0.03	0.03	....	....	....
Labourer	....	....	....	....	....	....	....	....	....	....	....	....	0.70	0.80	0.95

TRANSACTIONS

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DREDGES: THEIR CONSTRUCTION AND PERFORMANCE.

HYDRAULIC DREDGING ON THE MISSISSIPPI RIVER.

By F. B. Maltby, M. Am. Soc. C. E.

The improvement of low-water navigation on the Mississippi River by the removal of obstructing sand bars is a subject which has been under consideration for many years by a great many people, both engineers and laymen. A great many plans have been tested, and a vastly greater number have been proposed, many of them by persons having no definite understanding or realization of the difficulties of the problem. These numerous plans, both tried and untried, would furnish material for a very interesting discussion on the general subject of the improvement of the Mississippi River, but have no place in the present discussion.

The explanation of why sand bars exist and how they are formed, their causes and effects, is also an interesting problem. These bars or ridges of sand usually extend diagonally across the river, and lie between the lower end of a deep pool along the bank on the convex side of a bend and the upper end of the pool along the bank on the opposite side of the river bending in the opposite direction; *i. e.*, they usually occur where the thread of the channel

changes its direction of curvature. They are complicated by the existence of islands and secondary channels.

These bars, during seasons of high water, are built up to such an extent that during even a medium stage their crests may have an elevation several feet above that of the water surface at low water. As the river falls, these bars are cut out by the action of the current, and, to assist in this tendency of the river to deepen itself is the province of the dredges.

In a very able paper* on "Dredges and Dredging on the Mississippi River," J. A. Ockerson, M. Am. Soc. C. E., Member of the Mississippi River Commission, gives an interesting description of the various mechanical devices which had been proposed for deepening the channel of the river.

The writer proposes to confine himself strictly to the development of the hydraulic dredges belonging to the Mississippi River Commission and operated on that portion of the river below the junction of the Ohio and the Mississippi at Cairo, Illinois. The general subject of dredging is to be treated by A. W. Robinson, M. Am. Soc. C. E., whose experience in design and construction covers a vast range of dredges for widely different service.

The Mississippi River Commission, which is charged by the General Government with the work of improvement of the Mississippi below Cairo, first entered into the project of deepening the channel over the bars by dredging in 1892, when the dredge *Alpha* was constructed. From a consideration of the great extent of the obstructing bars, both in number and dimensions, it was realized that, in order to achieve results by dredging which would be of practical value, the magnitude of the work required would necessitate the construction of dredges of greater capacity, and capable of handling material at a lower unit cost, than any then in existence.

The *Alpha* was an experimental dredge and of comparatively small capacity, but her operation and the numerous tests made with her demonstrated conclusively the practicability of opening and maintaining suitable channels through obstructing bars at low water by dredging, and at a reasonable cost.

The *Alpha* has been followed by the construction of the *Beta, Gamma, Delta, Epsilon, Zeta, Iota, Kappa* and *Henry Flad;* the

* Presented at the Annual Convention of the American Society of Civil Engineers' in 1898, *Transactions*, Am. Soc. C. E., Vol. XL., p. 215.

latter being named in honor of the late Henry Flad, Past-President, Am. Soc. C. E., a member of the commission, and who designed, very largely, the *Alpha* and, until his death in 1898, was an active member of the Dredging Committee.

The *Beta*, at the time of her construction, was the cause of considerable interest to the Engineering Profession, as at that time she was the largest dredge in the world.

The *Alpha* was operated until 1898, but, owing to the facts that she could dredge only to a depth of 12.5 ft., that her capacity was comparatively small, also that her hull was of wood, she was dismantled in 1901, thus leaving the last eight dredges available for use at present. Mr. Ockerson's paper, to which reference is made, contains a detailed description of the dredges, from the *Alpha* to the *Zeta*, also an account of certain capacity tests made when they were constructed. Their description will not be repeated, except in a brief and general way, and to call attention to comparisons between certain features.

The *Beta* stands in a class by herself, owing to her size and to the fact that she has two independent pumps and operating engines. Her main sand pumps are also of radically different design, as will appear later. She also has the distinction of having required more extensive alterations to fit her for practical and continuous operation than any other. She was completed, ready for testing, in January, 1896, but many repairs and alterations were necessary, even before she could undergo the capacity tests successfully, as is made evident by the fact that out of 742 working hours consumed in these tests, 217 hours were used in actual pumping, 289 hours in repairs and necessary changes, and the remainder in towing, placing plant, handling material, getting ready, etc., time lost not through any defect in the dredge. The most serious defect in the dredge, however, was in the excessive draft. The specifications limited this to 4.5 ft., while the actual draft was about 6.5 ft.

She was operated through the low-water season of 1896 and 1897, but with many delays due to repairs. In 1898 numerous alterations were made, as follows:

1.—The hull was widened 9 ft. on each side and the new portions were carried forward of the old hull about 36 ft., forming a well for the suction heads; the stern was also extended about 6 ft.

2.—One battery of boilers was turned around.

3.—The discharge pipes from the sand pumps were removed from their former position overhead and placed on the floor of the hold.

4.—The heavy and complicated mechanical agitators were discarded, and new suction heads, with water-jet agitators, were built.

5.—Two triple-expansion, duplex, pressure pumps for serving the jet agitators were installed.

6.—The position of the filters and filter pumps was changed.

7.—The hoisting and hauling engines were discarded and new ones were installed.

8.—Three large steam capstans were installed.

9.—The position of the feed-water heater and pumps was changed.

10.—A cabin, with accommodations for a double crew, was built.

In addition, a great many minor details were changed, and additions were made. In fact, about the only features of the original dredge which were not changed were the boilers, main engines and main sand pumps.

The defects in this dredge have been enlarged upon because much has been said of her wonderful capacity and performance. She is a machine of great capacity, but her economical and regular operation has been attained only after many radical changes in the original design.

The five dredges, *Beta* (as rebuilt), *Gamma, Delta, Epsilon* and *Zeta,* have general characteristics which are very similar. They have steel hulls, rectangular in plan and cross-section, from 138 to 214 ft. long, from 38 to 58 ft. in width, and about 7 ft. in depth. At the bow the hull is recessed for a depth, fore and aft, of about 30 to 35 ft. This recess has a slightly greater width than the suction head, and forms a well protecting the head and within which it is raised and lowered.

The sand pumps are located near the bow and are driven by direct-connected, modern, high-speed, compound or triple-expansion engines. All the pumps except that on the *Delta* have double suction or intake pipes leading forward to the bow bulkhead, where they are joined to the pipes contained in the suction head by hinged, telescopic joints. These joints permit the raising or lowering of the outer end of the head to any position within their range

of movement, depending, of course, on the length of the head. The outer end of the suction head or shoe is flattened and widened to a width of from 21 ft. on the *Gamma* to 42 ft. on the *Beta.* The suction head is of such length as to permit of dredging to a depth of 18 ft. on the *Epsilon* and *Zeta,* 20 ft. on the *Gamma* and *Delta.* and 36 ft. on the *Beta,* as now arranged. The under side of the suction heads, at their forward or outer ends, has nozzles from 2.5 to 3.5 ft. apart, pointing forward. These nozzles have an inside diameter of from 1 to 2.5 in., and are supplied with water under pressure by either centrifugal or reciprocating pumps.

Each dredge, near the bow, has an oak spud, 22 by 22 in., for the purpose of holding the dredge in position while attaching hauling cables to the mooring piles, or while changing the position of the piles.

On the deck near the bow there are two powerful hauling engines which handle cables attached to piles and by which the dredge is hauled over the bar which is being dredged. There are also hoisting engines for handling the suction head and the spud.

The discharge pipe leads from the pump along the bottom of the hull to the stern of the dredge, and to the floating discharge pipe. This pipe is built in sections of about 50 ft., though the *Beta* has some 100-ft. sections. The pipe is supported by pontoons, formed either of circular, closed pipes, attached to each side of the discharge pipe by yokes, or by oval-shaped buoyancy chambers, partially surrounding the pipe and riveted to it. The sections of pipe are connected by rubber joints about 3.5 ft. long, which allow a certain amount of deflection between adjoining sections. The rubber joint is relieved of any pulling strain by draw-bars between each section.

The boilers are near the after end of the dredge. In addition to the foregoing machinery there is the necessary equipment of condensers, feed pumps, capstans, electric light plant and a complete machine and blacksmith shop.

The second, or cabin, deck has comfortable and commodious quarters for a double crew.

These dredges were designed in detail by the contractors, under very general specifications by the Government, which specifications contained certain requirements as to size, capacity, draft, equipment, etc.

The dredge *Iota,* built in 1899, was constructed from plans prepared in the office of the Commission, leaving to the contractors the design of the details of the main engines and sand pump, but confining these details to very narrow limits. On the *Kappa* and *Flad* the detailed plans of the sand pump were also prepared in the office of the Commission. The auxiliary machinery is of standard commercial make.

The three last-named dredges differ from the former ones principally in the fact that they are self-propelling and are larger and more powerful machines. Many details of design which have been found weak in the operation of the older dredges have been corrected in the later ones, and they have proved extremely satisfactory in operation and maintenance.

The *Kappa* and the *Henry Flad* were built from the same plans, and are alike. They have steel hulls, of the following dimensions:

Length, moulded	192 ft.
Width, "	44 "
Depth, "	7 "
Width at bow	32 "
Width at stern	34 "
Width over guards outside nosing	75 "
Length of well	33 "
Width of well, at nose	25 "

The framing is on the transverse system, with six transverse bulkheads and four longitudinal truss frames.

The hull frames are spaced at a uniform distance apart of 18 in.; the odd numbered ones are of 3 by 2.5-in., 5.5-lb. angle bars, and the even numbered ones are built up of two 2.5 by 2.5-in. angles, joined by plates 8 in. deep. The deck beams are alternately of 6-in. Z-bars and 3 by 2.5-in. angles. The hull plating is from $\frac{1}{4}$ to $\frac{5}{16}$ in. in thickness. All machinery is on the deck, nothing being carried in the hold but pipes and capstan engines.

The main sand pump has a runner, 84 in. in diameter and 25 in. wide, and is of the shrouded or enclosed type. The pump casing is rectangular in cross-section, and is provided with renewable liners throughout. It has a discharge pipe, 32 in. in diameter, and two suction pipes, 24 in. inside diameter.

The pump is driven by a pair of horizontal, tandem, compound, condensing engines, with cylinders 16 and 30 in. in diameter and 24-in. stroke, running about 135 rev. per min. The condenser and air-pump is of the independent-jet type, compound, duplex, non-condensing, with steam cylinders 10 and 17 in., water cylinders 19 in. in diameter and 15-in. stroke.

The propelling wheels are of the paddle-wheel type, one on each side, 22 ft. in diameter and 13 ft. long. They are driven by simple, direct-connected engines having cylinders 22 in. in diameter and 7-ft. stroke.

The steam plant consists of seven boilers, of the Mississippi River type, 44 in. in diameter, 30 ft. long, having four flues, 11 in. in diameter. They carry steam at 170 lb. per sq. in.

The suction head or shoe is about 23 ft. 6 in. in width, is flattened down to a depth of about 8 in. at the smallest part, and has a flaring entrance. The under side of the head is provided with a pressure chamber, into which there are screwed twelve 1-in. nozzles, distributed throughout its length, forming the jet agitator for loosening the sand or material to be dredged. These jets are supplied with water by a compound, duplex, condensing pump, with steam cylinders 10 and 20 in. in diameter, water plungers 16 in. in diameter and 15-in. stroke, and are operated against a pressure of from 40 to 70 lb. The pipes leading to the suction head are of such length as to permit its being lowered to a depth of about 20 ft. below the water surface. The head is raised and lowered by a double, reversing hoisting engine. The main hauling engines are on each side of the boat, near the bow, and have 7 by 7-in. cylinders, geared to the drum in the ratio of about 412 to 1. The drums are 48 in. in diameter, grooved, and have 1 200 ft. of 1-in. steel-wire rope.

Each dredge is supplied with steam capstans, the necessary auxiliary pumps, etc., a machine and blacksmith shop, electric lighting plant and a refrigerating plant having a capacity of about one ton of ice per day. The upper or cabin deck has commodious and comfortable quarters for a double crew consisting of about fifty men. The general arrangement of the machinery follows closely that of the dredges described previously.

These three latter dredges are entirely self-contained, and require

no outside assistance for their propulsion or operation. The mooring piles, when not in use, are suspended from derricks at the bow of the boat. These piles are simply sections of 11-in. extra-heavy pipe, and are 35 ft. long; their upper ends are closed, and can be connected, by 2.5-in. fire-hose, to a powerful pump. The lower end of the pipe is left open.

They are driven by forcing a strong stream of water through them. The weight of the piles, and the water issuing around their lower edges, sinks them into the sand very rapidly. They are usually sunk to a penetration of about 15 ft., and are supplied with clamps near the bottom of the river to which the hauling cables are attached. During this operation the dredge is held in position by the spud.

This feature of self-propulsion is the most important advance in the development of dredging on this river. In their operation, no larger crew is required than on a non-propelling dredge of the same size and capacity, and the expense of a large towboat and pile-driver, with their attendant crews, is obviated. Their operation is also very much more expeditious.

A summary of the general dimensions of the dredges mentioned is given in Table 29.

With this rather brief and general description of the dredges, it is proposed to discuss somewhat in detail certain of the most important features which are characteristic of hydraulic or suction dredges and which have been developed during their operation on this river.

The Sand Pump.

The most important feature of a hydraulic dredge is the main sand pump, and, as there is a very wide variation in practice as to the form and dimensions of the pump runner, it will be interesting to note the characteristics of the various pumps which are or have been in use on the various dredges described, with a comparison of the results obtained with each.

Tests for Capacity and Efficiency.—On the completion of the experimental dredge *Alpha,* a great many tests were made to determine her capacity and efficiency. Owing to the immense amount of material moving constantly along the bottom of the river, and

the scouring effect of the current, it was impracticable to ascertain, with accuracy, the amount of material pumped by measuring it in place. Therefore, a measuring barge was fitted up, to attach to the lower end of the discharge pipe, and, by suitable valves, the discharge could be led either overboard or into the barge, at will. This barge and the connecting valves are described in detail in Mr. Ockerson's paper, previously referred to. Briefly, the barge was 107.5 ft. long, 24 ft. wide and 6.5 ft. deep, and was provided with suitable wells and valves for drawing off the water within the barge without disturbing the sand deposited therein. The necessary gauges for determining the height of the sand and water were also provided and a very ingenious valve whereby the discharge could be deflected almost instantaneously. Precautions were taken to prevent leakage and to insure that all the discharge deflected into the barge would be measured.

In making a test, the dredge pumps were started, the suction head lowered into the sand, and the dredge pulled ahead as in actual work, the barge-valve being set to discharge into the river. When everything was running smoothly, and at a preconcerted signal, the barge-valve was thrown to discharge into the barge and at the same instant a stop-watch started. When all the material that the barge would safely hold had been discharged, the barge-valve was thrown to discharge into the river, the stop-watch being stopped at the same time. During the time the material was being pumped into the barge, indicator cards were taken on the engines, the suction head and discharge head at the pump were noted, and the steam pressure and number of revolutions of the engines were noted and recorded.

After a few minutes' time, to allow the agitated water in the barge to settle down, the gauges were read, showing the total height of material pumped, sand and water; this height into the known area giving the total volume pumped. The water was then drawn off, leaving the sand to be measured; this was done by measuring the depth at eleven points on each of eleven cross-sections; the average depth into the known area giving the volume of sand. Samples of sand from each test were dried and weighed carefully, and the percentage of voids obtained.

The suction pressure was measured by a piezometer, inserted in the suction pipe and connected with a manometer filled with

	Alpha.	*Beta.*	*Gamma.*	*Delta.*
Hulls:				
Material.	Wood.	Steel.	Steel.	Steel.
Length.	140 ft.	214 ft.	138 ft.	175 ft.
Breadth.	36 ft.	58 ft.	38 ft.	38 ft.
Depth.	8 ft.	6 ft. 11 in.	7 ft. 10 in.	8 ft. 4 in.
Draft.	59 in.	48 in.	54 in.	54 in.
Displacement.	640 tons.	1 280 tons.	640 tons.	930 tons.
Propell'g Machin'y:				
Engines, type.	None.	None.	None.	None.
Engines, diameter of cylinders.	....	....	....	....
Engines, stroke.	....	....	....	....
Paddlewh., diam.	....	....	....	....
Paddlewh., width.	....	....	....	....
Main pump. engines:				
Number.	One.	Two.	One.	One.
Type.	Vert. comp.	Vert., triple exp., cond.	Horiz., cross-comp., cond.	Vert., comp. cond.
Diam. of cylinders.	15 and 27 in.	20½, 33, 38, 38 in.	18 and 32½ in.	22 and 48 in.
Stroke.	20 in.	24 in.	22 in.	24 in.
Rev. per min.	150	140 in.	150	145
Steam pr. allowed.	160 lb.	175 lb.	140 lb.	175 lb.
I. H. P.	400	1 850	475	1 000.
Air pumps:				
Type.	None.	Duplex.	Single.	Single.
Cylinders.	....	14 in.	10 in.	12 in.
Air pump.	....	19 in.	18 in.	18 in.
Stroke.	....	15 in.	18 in.	24 in.
Main pumps:				
Number.	One.	Two.	One.	One.
Type.	Single suction.	Double suction.	Double suction.	Single suction.
Diam. of runner.	66 in.	84 in.	69 in.	84 in.
Peripheral velocity, per min.	2 421 ft.	3 080 ft.	2 712 ft.	3 080 ft.
Ditto per sec.	40 ft.	51 ft.	45 ft.	51 ft.
Diam. of suction.	30 in.	33¾ in.	24½ in.	34 in.
Width of suction mouth.	7 ft. 6 in.	38 ft. 8 in.	19 ft.	33 ft. 6 in.
Max. working depth of suction.	13 ft.	36 ft.	20 ft.	20 ft.
Diam. of discharge	30 in.	33 in.	34 in.	34 in.
Nominal capacity, sand per hour.	500 cu. yd.	1 600 cu. yd.	800 cu. yd.	800 cu. yd.
Average of tests, sand per hour.	1 070 cu. yd.	....	1 523 cu. yd.	1 850 cu. yd.
Sand per hour per I. H. P.	2.7 cu. yd.	....	3.28 cu. yd.	1.62 cu. yd.
Sand agitators:				
Type.	Water-jet.	Water-jet.	Water-jet.	Water-jet.
Type of pump.	Helical.	2 du., triple-exp.	Centrifugal.	2 du. comp. non-con.
Size.	15 in.	16 in.	18 in.	16 x 12 in.
Diam. and stroke.	8 x 16 x 12 in.	8, 14½ and 24 x 15 in.	12 and 22 x 14 in.	8½ x 16 x 12 in.
Number of jets.	6	18	13	18
Diam. of jets.	2½ in.	1 in.	1¾ in.	¾ in.
Pressure.	9 lb.	50-80 lb.	12-20 lb.	40-50 lb.
Electric light plant:				
Type of engine.	Horiz. belt-conn.	Vert., direct-conn.	Horiz., belt-conn.	Vert., belt-conn.
Diam. of cylinder.	6 in.	7 in.	8 in.	7 in.
Stroke.	10 in.	7 in.	10 in.	9 in.
Type of gener.	4-pole.	4-pole.	4-pole.	4-pole.
Capacity.	9 kw.	15 kw.	12 kw.	9 kw.
Searchlights.	1	2	1	1
Arc lights.	3	....	4	2
Incandes. lights.	70	125	75	100
Boilers:				
Number.	4	4	6	4
Type.	"Miss. Riv."	Heine water-tube.	"Miss. Riv."	Heine water-tube.
Diam.	42 in.	....	48 in.	....
Length.	28 ft.	....	28 ft.	....
Tubes, number and diam.	5, 10 in. diam.	171, 3½ in. diam.	5, 11 in. diam.	140, 3½ in. diam.
Tubes, length.	28 ft.	16 ft.	28 ft.	16 ft.
Tot. heating surf.	1 630 sq. ft.	8 964 sq. ft.	2 572 sq. ft	8 184 sq. ft.
Total grate surf.	72 sq. ft.	216 sq. ft.	137½ sq. ft.	213 sq. ft.
Ratio.*	22.6	41	18.7	38.3
Crews:				
On Dredge.	44	56	44	44
On large tender.	26	26	26	26
On small tender.	16	16	16	16
On pile sinker.	7	7	7	7
Gen. Contractors:	Hired labor.	Lindon W. Bates.	J. S. George.†	New York Dredging Co.
Contract price.	$90 000	$172 775	$85 530.60	$124 940
When completed.	July, 1895.	January, 1896.	August, 1897.	August, 1897.

* Ratio of heating surface to grate surface. † and H. P. Ellis, Receivers, Bucyrus S. S. & D. Co.

Epsilon	*Zeta.*	*Iota.*	*Kappa.*	*Henry Flad.*
Steel.	Steel.	Steel.	Steel.	Steel.
157 ft.	157 ft.	192 ft.	192 ft.	192 ft.
40 ft.	40 ft.	44 ft.	44 ft.	44 ft.
7 ft. 6 in.	7 ft. 6 in.	7 ft.	7 ft.	7 ft.
46 in.	46 in.	48 in.	48 in.	48 in.
665 tons.	665 tons.	....	....	....
None.	None.	"Miss. Riv."*	"Miss. Riv."*	"Miss. Riv."*
....	....	22 in.	22 in.	22 in.
....	....	6 ft.	7 ft.	7 ft.
....	....	21 ft.	22 ft.	22 ft.
....	....	10½ ft.	13 ft.	13 ft.
Two.	Two.	Two.	Two.	Two.
Horiz., tan., comp., non-cond.	Horiz., tan., comp., non-cond.	Horiz., tan., comp. cond.	Horiz., tan., comp., cond.	Horiz., tan., comp., cond.
16 and 26 in.	16 and 26 in.	16 and 26 in.	15 and 30 in.	15 and 30 in.
18 in.	18 in.	20 in.	24 in.	24 in.
180	180	165	140	140
140 lb.	140 lb.	160 lb.	170 lb.	165 lb.
750	750	800	850	850
None.	None.	Duplex comp.	Duplex comp.	Duplex comp.
....	....	10 and 17 in.	10 and 17 in.	10 and 17 in.
....	....	19 in.	19 in.	19 in.
....	....	15 in.	15 in.	15 in.
One.	One.	One.	One.	One.
Double suction.	Double suction.	Double suction.	Double suction.	Double suction.
69 in.	69 in.	75 in.	84 in.	84 in.
3 505 ft.	3 505 ft.	....	....	....
58 ft.	58 ft.	....	....	....
24 in.	24 in.	24 in.	24 in.	24 in.
20 ft.	20 ft.	23 ft.	23 ft.	23 ft.
18 ft.	18 ft.	18 ft.	18 ft.	18 ft.
32 in.	32 in.	32⅛ in.	31⅞ in.	32 in.
1 000 cu. yd.	1 000 cu. yd.	1 000 cu. yd.	1 000 cu. yd.	1 000 cu. yd.
2 553 cu. yd.	1 364 cu. yd.	....	....	....
3.38 cu. yd.	1.98 cu. yd.	....	....	....
Water-jet.	Water-jet.	Water-jet.	Water-jet.	Water-jet.
Centrifugal.	Centrifugal.	Duplex comp. con.	Duplex comp. con.	Duplex comp. con.
15 in.	15 in.	16 x 15 in.	16 x 15 in.	16 x 15 in.
12 and 22 x 12 in.	12 and 22 x 12 in.	10 x 20 x 15 in.	10 x 20 x 15 in.	10 x 20 x 15 in.
10	10	12	12	12
2 in.	2 in.	¾ in.	¾ in.	¾ in.
8-9 lb.	8-9 lb.	50 to 80 lb.	50 to 80 lb.	50 to 80 lb.
Horiz., direct-conn.	Horiz., direct-conn.	Vert., direct-conn.	Vert., direct-conn.	Vert., direct-conn.
5 in.	5 in.	8 in.	8 in.	8 in.
6 in.	6 in.	6 in.	9 in.	9 in.
4-pole.	4-pole.	4-pole.	4-pole.	4-pole.
21 kw.	12 kw.	15 kw.	15 kw.	15 kw.
1	1	2	2	2
2	2	2	2	2
75	75	100	100	100
6	6	7	7	7
"Miss. Riv."	"Miss. Riv."	"Miss. Riv."	"Miss. Riv."	"Miss. Riv."
48 in.	48 in.	44 in.	44 in.	44 in.
28 ft.	28 ft.	30 ft.	30 ft.	30 ft.
3, 11 in. dia. & 2, 13 in.	3, 11 in. dia., & 2, 13 in.	4, 11 in. diam.	4, 11 in. diam.	4, 11 in. diam.
28 ft.	28 ft.	30 ft.	30 ft.	30 ft.
3 000 sq. ft.	3 000 sq. ft.	3 769 sq. ft.	3 830 sq. ft.	3 830 sq. ft.
143 sq. ft.	143 sq. ft.	157.5 sq. ft.	157.5 sq. ft.	157.5 sq. ft.
21	21	23.9	24.3	24.3
44	44	48	48	48
26	26	....	....	....
16	16	....	....	....
7	7	....	....	....
Springfield Boiler & Mf'g. Co.	Springfield Boiler & Mf'g. Co.	Springfield Boiler & Mf'g. Co.	Bucyrus Co.	Bucyrus Co.
$102 000	$106 000	$98 820	$122 400	$122 400
March, 1898.	March, 1898.	August, 1901.	July, 1901.	July, 1901.

* Side-wheel.

mercury. The discharge head or pressure was measured by a piezometer inserted in the discharge pipe, near the pump, and connected to a manometer, filled in some instances with water and in others, where the head was large, with mercury. All pressures were reduced to feet of water and to the center of the pipes.

From these observations the various functions of capacity, velocity of discharge and efficiency were determined. This barge was afterward used in making tests of the pumps on the *Beta, Gamma, Delta, Epsilon* and *Zeta,* and the results have been published.*

The tests of pumps on all the dredges except the *Beta* were made by C. W. Sturtevant, M. Am. Soc. C. E., who was in charge of the operation, care and maintenance of the dredges from 1893 to 1898 and from 1899 to 1902, and to his energy and ability is due, in a very large measure, the success of these operations. The tests of the *Beta* were made under the direction of William Gerig, M. Am. Soc. C. E., who had also acted as inspector for the Government during her erection. The observations were made with great care by reliable observers, and, from a considerable personal knowledge of methods used, the writer has great confidence in their accuracy. On the *Beta* alone the writer believes the results given have very little value except to show that, under peculiarly favorable circumstances and for a very short interval of time, the dredge has an enormous capacity. The tests were made for the contractor's benefit, and he was allowed to select the locality for testing and indicate by signal just when the measurements should be made. The results, as far as the efficiency of the pumps is concerned, are absolutely valueless; because, although the discharge of both pumps was measured, the indicated horse-power developed was measured on only one engine and this quantity doubled to obtain the total power, although the speed of the two pumps varied as much as 17 rev. per min. in one test.

Mr. Gerig writes concerning these tests as follows:

"One of the requirements of the specifications of the dredge *Beta* was: Before the dredge and dredging plant are accepted and paid for by the Government it shall be subjected to the following tests:

"First. A test for determining the capacity of the pumps to lift and discharge material. This test shall be made by placing the

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* Annual Reports, Chief of Engineers, U. S. A., for 1895 to 1898.

dredge at work at some point on the river, fixed by the United States Engineer, where an ordinary river sand may be obtained at the average depth of cutting.

"They shall discharge through 1 000 ft. of pipe each, with the pumps running at their average speed and without applying forced draft to the boilers, into a barge fitted up for the purpose, in such a way as to determine separately the respective amounts of sand and water discharged per hour.

"The programme prescribed for making the tests, the measuring barge, and other appliances used were the same as previously employed in successfully testing the dredge *Alpha,* and were ample except steam indicators, of which only a sufficient number were available to obtain cards from one engine.

"The contractor, from a lack of confidence in his figures or estimates of the pumps' capacities, interposed so many objections to the method of making the tests, although he had agreed to the above clause of the specifications, and was familiar with the tests of the *Alpha* and also to the various points fixed by the United States Engineer officer for placing the dredge at work, so that, finally, after a large amount of preliminary work had been done by the dredge, and after the first official barge test had been made, it was decided to permit him to select the bar where the work should be done and to indicate when the discharge should be turned into the barge.

"The contractor, of course, did not fail to have the conditions most favorable before he would declare his readiness for the test to begin and such conditions are never encountered in actual field operations.

"In making a capacity test, the dredge was first operated for some time, in order that all of the machinery was known to be in good working condition, then, when the discharge pipes were well loaded, and in test No. 5 they were sinking, the contractor would declare his readiness for the tests to begin. The pontoons had a capacity to carry material composed of water and about 50% sand.

"When discharging into the river while the barge was connected, the stream had to make a right-angle turn at the barge, but when the valves were opened it flowed in a straight line, being a continuation of the axis of the discharge pipe, into the barge.

"As soon as the valves were opened the discharge pipes did rise at the measuring barge and continued rising toward the dredge until the valves were closed again, although the rate of advance and the depth of the suction head had not been changed. The speed of the main pumping engines, however, did increase, although the throttle valve had not been touched. These facts were carefully noted by observers stationed at the various points for this special purpose.

"When the pontoons, by their submergence, show that the material being transported contains from 30 to 50% or more of sand, a large portion of the heavier particles in the bottom half of the pipe is moving at a very low velocity, or probably not moving at all, and a sudden removal of a certain amount of head at the end of the pipe acts as a relief and permits the material to be discharged more rapidly. This reduction of head at the end of the pipe occurred when the flow of the discharge was changed to a straight line. The amount of reduction was the head required to overcome the friction developed by the stream flowing through 90° of curvature having a very short radius. The amount of this head was probably more than that ordinarily required at a 90° ell, since the sides of the valve chamber were square and the valve alone was curved. This probably explains the cause of the reduction of the submergence of the pontoons when the valve was opened.

"Your attention is called to the fact that the time required to fill the measuring barge was, in most cases, less than that required for transporting the material from the pump to the barge, and, therefore, the pump may possibly have been handling a material of entirely different density than that actually delivered in the barge; and the data, which were obtained at the pump and engine simultaneosly with the opening of the valve, are, to say the least, suspicious.

"The contractor was given these privileges only after it had been determined, from a large number of observations on the cuts made, that the capacity of the dredge was ample to fulfill the requirements of the specifications."

Although, as stated previously, the writer has every confidence in the observations made, he believes the reductions of data and results, as published, in so far as efficiency of pumps is concerned, are seriously in error. Inasmuch as these reductions and computations were made under the direction of that eminent engineer, Col. Henry Flad, the writer attacks them with considerable diffidence, and begs to submit his reasons in considerable detail.

In computing the amount of work done by the pump, it is important to have a very clear understanding of just what work the pump is to be credited with and how it is indicated.

In any case, the work done by the pump is equal to $Q \times W \times H$, where

Q = volume of material pumped per unit of time;

W = weight per unit volume of material pumped;

H = total head, $= h_D + \frac{v_d^2}{2g} + h_S - \frac{v_S^2}{2g}$ ....(1)

in which,

h_D = head on discharge pipe, in feet of material pumped;

h_S = head or vacuum on suction pipe, in feet of material pumped;

v_D = velocity in discharge pipe, in feet per second;

v_S = velocity in suction pipe, in feet per second.

Q, W, h_D and h_S are factors determined by direct measurement and observation; and v_D and v_S are computed from Q and the known area of the suction and discharge pipes.

It remains, then, to show that the total head, H, is made up of the quantities in Equation 1.

The total energy imparted to the fluid (and, in this case, by fluid is meant the mixture being pumped, be it pure water or sand and water) is expended, outside the pump itself, in overcoming entrance head, friction in pipes and actual lift, and in creating velocity, and all this is included in the term, head.

It is generally accepted that on a pipe flowing under pressure a piezometer will indicate all the head except the velocity head. On a suction pipe, however, a piezometer gives the total head on the pipe, including the velocity head. This fact is shown quite clearly by Mr. W. M. White, in the *Journal of the Association of Engineering Societies,* October, 1900, where he proposed to, and did, measure velocities by piezometers in the suction pipes of centrifugal pumps. This fact is also shown quite clearly by Professor W. B. Gregory, of Tulane University, in a report to the Mississippi River Commission, as follows:

"Referring to figure (Fig. 19), let two tanks K and L be connected by a pipe of uniform cross-section in which water flows with a constant velocity v when the level of the water in tank K is at A. Suppose a suitable supply provided for tank K or that the water level is always kept at A; also an outflow provided for tank L, so that water may be discharged into L and a desired height always maintained.

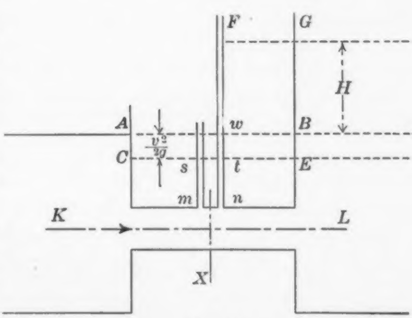


FIG. 19.

"Now, neglecting losses due to friction in pipe at entrance, etc., the "hydraulic gradient" would take

the position of line $C\ E$, and this would be the level of the water in the tank, L, to maintain continuous flow at a velocity of v feet per second. $A\ C = B\ E = \frac{v^2}{2g}$. Let two piezometers be placed in pipe at m and n; the level in these piezometers would be s, t.

"Suppose at section X we cut the pipe and introduce a pump. which will always maintain the uniform velocity v in the pipe and also deliver the water into tank L at a level $A\ B$. The level of water in discharge tank will then just equal that in suction tank, and the work of the pump will clearly be to produce the velocity head.

"At the left of section X the conditions are unchanged from those of the first case taken, for the constant velocity v is maintained.

"The height of the water in piezometer m will therefore be at s. On the right of section X the level of water in tank L is raised to B, and therefore the water in piezometer n will stand at w.

"The difference between the readings of the two piezometers will thus be seen to include the velocity head; in fact, in this case would be just equal to the velocity head.

"Again, if water is pumped into tank L and the level in tank is raised to G, while the same velocity v is maintained in suction and discharge pipes, the level of water in piezometer n would be at F, while in the piezometer m it would still stand at s; the difference between these two readings would plainly be $F\ G = \frac{v^2}{2g} + H$ and is seen to include the velocity head.

"The simplest possible case has been taken to prove this point; the proof still holds, however, if we consider all losses in the pipe.

"It will be seen that if section at m differs in size from that at n, the hydraulic gradient will not be a straight line; but in any case the velocity head which is included is that at m, *i. e.*, the velocity head corresponding to the velocity in suction pipe. The velocity head in discharge pipe will not be shown by piezometer, but may be computed. If it is more than that in suction pipe the difference must be added to suction and discharge heads; if less, it must be substracted."

If these facts concerning piezometers be accepted as true, and if the suction and discharge pipes are of the same size, then the total head, $H = h_D + h_S$.

The principal error, in the published results of the barge tests referred to, lies in the fact that, to the sum of the observed suction and discharge heads has been added the velocity head in the discharge pipe, thus crediting the pump with velocity head twice. On all the dredges except the *Delta* the suction pipes have a somewhat

greater area than the discharge pipe, and the difference of heads due to the velocities in the suction and discharge pipes should be added to the sum of the observed suction and discharge heads in determining the total head. On the *Delta,* the sizes are given as the same.

Another error, though not a large one, lies in the fact that, in some instances, though not in all, the head in feet of water was used, instead of in feet of the material being pumped, as should have been done.

Having in mind these errors, the writer has recomputed the published results, using the observed quantities as given, and submits the results obtained in Table 30. Column 16 is derived as follows:

A cubic foot of wet sand was assumed to weigh the given weight dry, plus the weight of water occupying voids; a cubic foot of the mixture pumped then weighs the percentage of sand pumped (Column 30) into the weight of wet sand, plus the weight of the remaining percentage of water into the weight of water, 62.5 lb. per cu. ft. The head of material pumped (Column 22) is to the total head of water observed (Column 21) as the weight per cubic foot of material pumped is to the weight of water. Column 24 gives the efficiency of the pump and engines, as based on the indicated horse-power developed. Column 25 gives the efficiency of the pump alone, assuming for the engines an efficiency of 90%, which does not seem unreasonable.

The characteristic features of these pumps are shown by Figs. 20, 21, 22, 23, 24 and 35.

In 1902 the Mississippi River Commission authorized the preparation of plans for an additional dredge, making the tenth in the series. As the dredges previously built had pumps of various types, each apparently recommended by different features, a series of comparative tests was authorized, to determine, if possible, a standard type, combining in the greatest degree efficiency, endurance and convenience of repair. These tests were placed under the direction of the writer, and were made during the low-water season of 1902 at such times as the dredges were not required for actual dredging and at such times as the writer could spare from his other duties as Superintendent of Dredging Operations.

Gamma.	80.4	162	143	505.4	2-24	6.28	11.62	2.10	34	6.30	11.59	2.08	73.07	Sand and water.	70.77	5 171	10.3	29.3	....	39.6	34.97
1897.	90.8	176	135	479.3	2-24	6.28	Same as discharge pipe.	Same as discharge pipe.	34	6.30	10.64	1.82	67.07		72.04	4 832	8.0	35.0	....	43.0	37.31
Chief of Engineers'	105.3	174	152	486.2	2-24	6.28			34	6.30	8.48	1.15	53.46		71.88	3 843	8.0	38.5	....	46.5	40.43
Rep., 1898, p. 3327.	81.2	163	162	436.9	2-24	6.28			34	6.30	11.37	2.00	71.69		66.47	4 765	7.5	30.0	....	38.6	36.29
	59.5	172	144	512.2	2-24	6.28			34	6.30	10.57	1.72	66.66		76.25	5 083	9.4	35.0	....	44.4	36.39
	40.6	165	139	477.6	2-24	6.28			34	6.30	9.79	1.48	61.76		75.89	4 687	9.6	38.7	....	48.3	39.78
	64.7	166	145	......	2-24	6.28			34	6.30	7.84	0.95	49.43		75.46	3 730	9.2	41.5	....	50.7	41.99
	67.2	170	130	482.6	2-24	6.28			34	6.30	9.42	1.37	59.40		80.25	4 767	8.6	41.5	....	50.1	39.02
	69.7	166	140	480.6	2-24	6.28			34	6.30	10.77	1.79	67.91		70.00	4 754	8.0	33.9	....	41.9	37.41
	97.6	167	143	......	2-24	6.28			34	6.30	5.15	0.41	32.46		76.17	2 472	14.3	45.4	....	59.7	48.99
	64.4	169	125	507.5	2-24	6.28			34	6.30	10.64	1.78	67.07		80.34	5 388	10.3	37.3	....	47.6	37.03
Delta.	77.0	150	159	1 035.1	34	6.30	Same as discharge pipe.	Same as discharge pipe.	34	6.30	16.19	4.1	102.05	Sand and water.	70.18	7 169	17.0	46.4	....	63.4	56.46
1897.	62.5	151	156	......	34	6.30			34	6.30	16.50	4.2	104.03		66.95	6 983	18.7	45.3	....	64.0	59.75
Chief of Engineers'	71.5	149	156	......	34	6.30			34	6.30	15.59	3.8	98.27		71.85	7 061	18.1	45.3	....	63.4	55.15
Rep., 1898, p. 3329.	79.0	151	156	1 030.9	34	6.30			34	6.30	12.69	2.3	76.24		72.80	5 551	19.2	54.5	....	73.7	63.27
	75.5	150	156	996.9	34	6.30			34	6.30	14.96	3.5	94.35		66.97	6 319	18.1	47.6	....	65.7	61.32
	61.0	149	160	1 098.6	34	6.30			34	6.30	14.71	3.4	92.78		76.00	7 057	19.8	45.3	....	65.1	53.47
	59.25	152	161	982.1	34	6.30			34	6.30	14.01	3.0	88.36		78.27	6 916	19.2	47.6	....	66.8	53.34
	61.0	149	160	918.2	34	6.30			34	6.30	15.41	3.7	97.19		68.46	6 654	17.0	47.6	....	64.6	58.97
	60.0	150	161	1 089.9	34	6.30			34	6.30	13.92	3.0	87.76		72.78	6 383	23.2	38.4	....	61.6	52.90
	60.5	149	156	......	34	6.30			34	6.30	15.01	3.5	94.65		79.65	7 539	19.2	43.0	....	62.2	48.81
	58.0	152	161	1 096.8	34	6.30			34	6.30	15.39	3.7	97.05		71.06	6 897	18.1	41.8	....	59.9	52.68
	60.5	151	156	1 045.8	34	6.30			34	6.30	14.68	3.3	92.54		70.22	6 498	17.5	43.0	....	60.5	53.85
	61.0	154	156	1 072.3	34	6.30			34	6.30	14.80	3.4	93.83		68.09	6 355	17.5	45.3	....	62.8	57.64
	72.0	154	156	1 069.2	34	6.30			34	6.30	15.10	3.5	95.23		68.25	6 499	18.1	46.4	....	64.5	59.07
Epsilon.	122.2	182	153	611.6	2-24	6.28	9.06	1.27	32	5.58	10.02	1.58	57.22	Mud, sand, and water.	68.82	3 938	13.0	44.7	0.31	58.01	52.68
1898.	102.5	181	160	642.0	2-24	6.28	13.05	2.56	32	5.58	14.7	3.35	81.95		67.47	5 529	15.8	34.7	0.79	51.29	47.51
Chief of Engineers'	82.6	181	155	712.4	2-24	6.28	15.01	3.48	32	5.58	16.9	4.42	94.48	Sand and water.	70.69	6 679	16.4	34.7	0.94	52.04	46.01
Rep., 1898, p. 3332.	54.5	182	155	775.7	2-24	6.28	13.94	3.01	32	5.58	15.7	3.82	87.65		65.31	5 724	18.1	37.7	0.81	56.61	54.17
	61.5	182	165	801.1	2-24	6.28	14.56	3.28	32	5.58	16.4	4.17	90.16		73.34	6 612	19.8	37.7	0.89	58.39	49.76
	66.4	181	160	738.3	2-24	6.28	14.74	3.36	32	5.58	16.6	4.28	92.48		74.59	6 838	17.0	37.7	0.92	55.62	46.61
	57.5	182	162	717.1	2-24	6.28	16.10	4.03	32	5.58	18.3	5.18	102.35		72.27	7 397	14.7	36.7	1.15	52.55	46.08
Zeta.	62.0	182	145	718.4	2-24	6.28	15.10	3.54	32	5.58	17.0	4.49	94.92	Sand and water.	70.13	6 657	13.0	34.7	0.95	48.65	43.36
1898.	60.0	182	150	689.1	2-24	6.28	12.96	2.60	32	5.58	14.6	3.32	81.75		69.12	5 650	12.4	35.7	0.72	48.82	44.15
Chief of Engineers'	69.6	182	146	678.2	2-24	6.28	14.65	3.33	32	5.58	16.5	4.22	91.91		70.91	6 517	10.2	35.7	0.89	46.79	41.24
Rep., 1898, p. 3333.	70.0	181	146	661.0	2-24	6.28	15.80	3.88	32	5.58	17.8	4.90	99.81		67.01	6 655	10.7	35.7	1.02	47.42	44.23
	61.6	180	144	688.0	2-24	6.28	14.65	3.34	32	5.58	16.5	4.22	92.09		67.84	6 217	11.3	33.7	0.88	45.88	42.27

TABLE 30.—CAPACITY TESTS OF CENTRIFUGAL SAND PUMPS, BY BARGE MEASUREMENT.

Name of dredge.	Duration of tests, in seconds.	Revolutions per minute.	Steam pressure, in pounds per square inch.	Indicated horse-power.	SUCTION PIPE. Inside diameter, in inches.	SUCTION PIPE. Area, in square feet.	SUCTION PIPE. Mean velocity, in feet per second.	SUCTION PIPE. Velocity head, in feet of water.	DISCHARGE PIPE. Inside diameter, in inches.	DISCHARGE PIPE. Area, in square feet.	DISCHARGE PIPE. Mean velocity, in feet per second.	DISCHARGE PIPE. Velocity head, in feet of water.	Discharge, in cubic feet per second.	Material pumped.	Weight per cubic feet of material pumped.	Discharge, in pounds per second.	HEADS. Suction, in feet of water.	HEADS. Delivery, in feet of water.	HEADS. Velocity, in feet of water.	HEADS. Total, in feet of water.	HEADS. Total feet of material pumped.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)
Alpha. 1894. Chief of Engineers' Rep., 1895, p. 3796.	150	118	154	319.0	30	4.91	Same as discharge pipe.	Same as discharge pipe.	30	4.91	13.31	2.75	65.33	Sand and water.	66.18	4 324	10.40	15.53	....	25.93	24.49
	138	118	153	319.0	30	4.91			30	4.91	11.10	1.90	54.49		70.26	3 829	10.56	15.80	....	26.36	23.45
	122	117	150	312.0	30	4.91			30	4.91	11.74	2.11	57.66		69.61	4 014	10.44	15.39	....	25.83	23.19
	140	116	143	291.0	30	4.91			30	4.91	11.74	2.11	57.64		67.71	3 903	9.80	15.38	....	25.18	23.24
	155	119	155	319.0	30	4.91			30	4.91	12.41	2.40	60.96		69.16	4 216	10.43	16.59	....	27.02	24.20
	138	118	150	319.0	30	4.91			30	4.91	12.04	2.23	59.14		66.92	3 961	10.18	15.23	....	25.41	23.73
	123	115	150	316.0	30	4.91			30	4.91	12.85	2.58	63.12		68.71	4 337	10.53	14.08	....	24.61	22.39
	135	118	150	314.0	30	4.91			30	4.91	11.48	2.02	56.38		68.26	3 849	10.09	15.90	....	25.99	23.80
	131	119	153	321.0	30	4.91			30	4.91	12.94	2.61	63.54		66.68	4 237	10.57	15.32	....	25.89	24.27
	183	123	146	306.0	30	4.91			30	4.91	9.78	1.48	48.04		65.92	3 163	8.06	22.13	....	30.19	28.62
	194	127	138	294.0	30	4.91			30	4.91	7.53	0.88	37.01		67.64	2 503	8.63	22.80	....	31.43	29.04
	197	130	140	299.0	30	4.91			30	4.91	7.85	0.96	38.57		70.58	2 722	7.27	22.64	....	29.91	26.49
	174	130	146	318.0	30	4.91			30	4.91	9.20	1.32	45.18		68.77	3 107	8.12	23.53	....	31.65	28.76
	193	125	130	274.0	30	4.91			30	4.91	8.94	1.24	43.85		67.29	2 951	7.30	25.52	....	32.82	30.48
	184	129	143	318.0	30	4.91			30	4.91	9.46	1.39	46.44		67.89	3 153	8.13	23.36	....	31.49	28.99
	180	120	140	300.0	30	4.91			30	4.91	10.79	1.80	52.98		68.42	3 625	8.70	20.72	....	29.43	26.88
Alpha. 1898. Chief of Engineers' Rep., 1898, p. 3341.	69.5	156	160	467.3	30	4.91	14.2	3.1	30	4.91	14.2	3.1	69.95	Water.	62.50	4 372	9.6	25.8	....	35.4	35.40
	95	152	165	453.3	30	4.91	13.9	3.0	30	4.91	13.9	3.0	68.14	Sand and water.	73.34	4 997	13.6	30.4	....	44.0	37.50
	93.5	159	165	337.7	30	4.91	9.6	1.4	30	4.91	9.6	1.4	47.34		71.00	3 361	7.4	35.0	....	42.4	37.32
	101.5	148	125	357.6	30	4.91	8.6	1.2	30	4.91	8.6	1.2	42.35		64.76	2 743	10.2	35.0	....	45.2	43.62
	101.5	155	156	397.2	30	4.91	11.4	2.0	30	4.91	11.4	2.0	56.22		69.26	3 894	10.2	32.7	....	42.9	38.71
	102	155	155	424.8	30	4.91	12.4	2.4	30	4.91	12.4	2.4	60.71	Water.	62.50	3 794	7.4	24.6	....	32.0	32.00
	101.5	157	160	361.8	30	4.91	7.2	0.8	30	4.91	7.2	0.8	35.80	Sand and water.	77.37	2 770	10.2	53.4	....	63.6	51.38
	120	162	158	329.9	30	4.91	3.9	0.2	30	4.91	3.9	0.2	19.19		74.25	1 425	9.1	38.5	....	47.6	40.07
	109	152	155	390.6	30	4.91	9.7	1.5	30	4.91	9.7	1.5	47.65		70.20	3 345	9.1	28.1	....	37.2	33.17
	68	152	160	475.9	30	4.91	14.1	3.1	30	4.91	14.1	3.1	69.04		71.84	4 958	14.2	30.4	....	44.6	38.80
Beta. 1896. Chief of Engineers' Rep., 1896, p. 3642.	35	150	170	2 561	33¾	6.20	20.00	6.42	33	5.94	20.77	6.70	246.8	Sand and water.	63.89	15 768	19.5	32.3	0.28	52.08	50.95
	69	157	160	2 593	33¾	6.20	11.41	2.11	33	5.94	11.89	2.20	141.6		71.03	10 058	17.55	40.9	0.09	58.54	51.51
	37	161	163	2 586	33¾	6.20	11.18	2.00	33	5.94	11.60	2.08	137.8		81.88	11 283	14.7	46.4	0.08	61.18	46.70
	65	148	168	2 447	33¾	6.20	13.10	2.80	33	5.94	13.78	2.92	163.5		75.59	12 359	15.8	39.0	0.12	54.92	45.41
	26	153	168	2 392	33¾	6.20	12.93	2.70	33	5.94	13.47	2.81	160.1		83.43	13 357	19.5	41.8	0.11	61.41	46.00
	56	151	164	2 609	33¾	6.20	13.40	2.91	33	5.94	13.97	3.03	165.9		75.04	12 449	18.4	37.5	0.12	56.02	46.66
	54	146	162	2 212	33¾	6.20	13.49	2.95	33	5.94	14.03	3.07	166.6		72.41	12 064	18.0	38.0	0.12	56.12	48.44
	50	148	160	2 496	33¾	6.20	12.99	2.71	33	5.94	13.52	2.83	160.6		78.61	12 625	20.9	37.1	0.12	58.12	46.21
	103	141	164	2 340	33¾	6.20	13.32	2.87	33	5.94	13.85	2.98	164.5		78.88	12 976	20.1	32.7	0.11	52.91	41.92
	96	144	167	2 398	33¾	6.20	14.32	3.30	33	5.94	14.92	3.44	173.9		74.76	12 973	19.8	33.2	0.14	53.14	44.52
	119	149	157	2 374	33¾	6.20	15.90	4.05	33	5.94	16.53	4.21	190.5		......	......	18.5	29.9	0.16	48.56	.....
	78	157	157	2 322	33¾	6.20	13.80	3.05	33	5.94	14.37	3.19	175.1		......	......	15.6	36.7	0.14	42.44	.....

Gamma.	180 850	65.06	72.29	69	48.77	48	1 069	14.3	98.5	37	0.9724	1 394	Pump built by Bucyrus, double-suction, 4 blades, open runner, direct-connected to cross-compound, condensing engines, 18 by 32.5 in., and 22-in. stroke.
1897.	180 252	68.38	75.98	69	52.99	48	1 069	16.0	99.0	37	0.9244	1 412	
Chief of Engineers'	155 367	58.10	64.56	69	52.39	48	1 069	15.8	105.5	33	0.9734	1 129	
Rep., 1898, p. 3327.	172 953	71.98	79.92	69	49.07	48	1 069	8.1	99.0	37	0.9845	776	
	184 982	65.66	72.96	69	51.76	48	1 069	22.2	103.5	36	0.9347	1 967	
	186 440	70.98	78.86	69	49.68	48	1 069	21.6	101.5	35	1.0182	1 780	
	156 632	.....	.....	69	49.98	48	1 069	21.4	103.0	34	1.0399	1 411	
	186 000	70.08	77.86	69	51.18	48	1 069	27.6	105.0	34	0.9788	2 184	
	177 836	67.28	74.75	69	49.98	48	1 069	13.2	99.5	33	0.9815	1 195	
	121 115	.....	.....	69	50.28	48	1 069	21.0	107.0	33	1.1086	910	
	199 535	71.49	79.43	69	50.88	48	1 069	29.0	106.0	36	0.9592	2 595	
Delta.	404 780	71.10	79.00	84	56.26	84.6	1 104.5	12.8	98.5	37	1.071	1 745	Pump built by New York Dredging Co., single suction, 5 blades, open runner, direct-connected to vertical, compound, condensing engine, 22 by 48 in., and 24-in. stroke.
1897.	417 200	.....	.....	84	56.63	84.6	1 104.5	11.7	76.5	37	1.095	1 621	
Chief of Engineers'	389 395	.....	.....	84	55.88	84.6	1 104.5	17.0	94.5	37	1.066	2 224	
Rep., 1898, p. 3329.	351 198	61.93	68.81	84	56.63	84.6	1 104.5	17.8	98.5	34	1.110	1 824	
	387 426	70.65	78.50	84	56.26	84.6	1 404.5	7.4	104.5	35	1.108	928	
	377 060	62.40	69.34	84	55.88	84.6	1 104.5	19.6	108.5	36	1.049	2 432	
	368 909	68.30	75.89	84	57.01	84.6	1 104.5	25.1	100.5	40	1.027	2 949	
	392 400	77.70	86.34	84	55.88	84.6	1 104.5	7.7	115.5	36	1.102	995	
	337 877	56.37	62.63	84	56.26	84.6	1 104.5	18.0	96.5	37	1.037	2 111	
	367 950	.....	.....	84	55.88	84.6	1 104.5	25.5	110.5	33	1.003	3 212	
	363 388	60.23	66.97	84	57.01	84.6	1 104.5	14.3	100.5	37	1.021	1 853	
	349 921	60.84	67.60	84	56.63	84.6	1 104.5	11.9	102.5	39	1.039	1 471	
	366 319	62.11	69.01	84	57.76	84.6	1 104.5	10.0	96.5	35	1.053	1 240	
	383 893	65.30	72.55	84	57.76	84.6	1 104.5	7.9	112.5	35	1.054	1 000	
Epsilon.	207 458	61.67	68.52	69	54.79	69	1 121	9.9	106.0	33	1.062	757	Pump built by Morris Machine Co., double-suction, 7 blades, open runner, direct-connected to pair of horizontal, tandem-compound, non-condensing engines, 16 by 26 in., and 18-in. stroke.
1898.	262 682	74.40	82.66	69	54.49	69	1 121	6.5	103.0	33	1.014	715	
Chief of Engineers'	307 300	78.43	87.14	69	54.49	69	1 121	13.6	100.2	36	0.9983	1 713	
Rep., 1898, p. 3332.	310 101	72.69	80.77	69	54.79	69	1 121	24.6	103.2	33	1.079	2 875	
	329 026	74.68	82.97	69	54.79	69	1 121	25.8	97.5	36	1.032	3 102	
	321 484	79.17	87.97	69	54.49	69	1 121	22.9	97.8	35	1.004	2 822	
	340 854	86.60	96.2	69	54.79	69	1 121	16.5	99.2	36	0.9936	2 255	
	288 616	73.07	81.18	69	54.79	69	1 121	14.8	100.0	36	0.9637	1 879	
Zeta.	249 443	65.81	73.13	69	54.79	69	1 121	11.9	95.0	37	0.9725	1 300	Pump built by Morris Machine Co., double-suction, 7 blades, open runner, direct-connected to pair of horizontal, tandem-compound, non-condensing engines, 16 by 26 in., and 18-in. stroke.
1898.	268 775	72.06	80.06	69	54.79	69	1 121	10.8	94.5	36	0.9399	1 329	
Chief of Engineers'	294 327	80.96	89.95	69	54.49	69	1 121	8.1	95.0	37	0.9788	1 071	
Rep., 1898, p. 3333.	264 065	69.68	77.42	69	54.19	69	1 121	10.1	93.0	35	0.9621	1 244	

TABLE 30.—(*Continued.*)

Name of dredge.	Work done, in foot-pounds per second. (22)	Percentage of efficiency of pump and engine. (23)	Efficiency of pump Engine efficiency assumed, at 90 per cent. (24)	Diameter of runner, in inches. (25)	Peripheral velocity, in feet per second. (26)	Length of suction pipe, in feet. (27)	Length of discharge pipe, in feet. (28)	Percentage of sand, wet. (29)	Weight of 1 cu. ft. of dry sand. (30)	Percentage of voids, in sand. (31)	$\frac{\sqrt{2gh}}{Vp}$. (32)	Cubic yards of sand per hour. (33)	Remarks. (34)
Alpha. 1894. Chief of Engineers' Rep., 1895, p. 3796.	105 875	60.35	67.05	76	39.13	101	604.5	5.63	106	35	1.0142	491	Edwards pump, three blades, closed runner, direct-connected to vertical compound, non-condensing engine, 15 by 27 in., and 20-in. stroke.
	89 772	51.17	56.85	76	39.13	101	604.5	12.45	104	$33\frac{1}{3}$	0.9925	905	
	93 085	54.25	60.27	76	38.80	101	604.5	10.89	104	38	0.9954	838	
	90 711	56.68	62.98	76	38.47	101	604.5	7.61	108	$36\frac{2}{3}$	1.0051	585	
	102 946	58.68	65.20	76	39.46	101	604.5	10.27	104	$37\frac{1}{3}$	1.0043	835	
	93 920	53.53	59.47	76	39.13	101	604.5	6.37	109	$36\frac{2}{3}$	0.9985	503	
	97 087	55.85	62.06	76	38.14	101	604.5	9.21	109	$33\frac{1}{3}$	0.9950	775	
	91 584	53.03	58.92	76	39.13	101	604.5	8.67	106	$36\frac{2}{3}$	1.0000	652	
	102 816	58.10	64.56	76	39.46	101	604.5	6.20	106	$38\frac{1}{3}$	1.0012	526	
	90 644	53.86	59.84	76	40.79	101	1 059.5	5.23	100	$41\frac{2}{3}$	1.0519	335	
	72 701	44.96	49.95	76	42.11	101	1 059.5	7.38	108	$38\frac{2}{3}$	1.0262	364	
	72 103	43.85	48.72	76	43.11	101	1 059.5	12.17	106	$36\frac{2}{3}$	0.9574	626	
	89 372	51.10	56.78	76	43.11	101	1 059.5	9.11	108	$37\frac{1}{3}$	0.9978	549	
	89 950	59.69	66.32	76	41.45	101	1 059.5	6.93	111	$34\frac{1}{3}$	1.0682	405	
	91 399	52.26	58.06	76	42.78	101	1 059.5	7.75	107	40	1.0094	446	
	97 450	59.06	65.62	76	39.79	101	1 059.5	8.90	103	$41\frac{2}{3}$	1.0449	629	
Alpha. 1898. Chief of Engineers' Rep., 1898. p. 3341.	154 764	60.22	66.91	66	44.92	66	599	....	......	..	1.0622	......	Tests of pump installed on *Alpha* in Sept., 1897, built by Morris Machine Co., open runner, having six blades, 66 in. diameter, 33-in. fan, direct-connected to vertical, compound, non-condensing engine, 15 by 27 in., and 20-in. stroke.
	187 382	75.16	83.51	66	43.77	66	599	18	104	30	1.1220	1 614	
	125 450	67.54	75.04	66	45.79	66	1 131	14	102	34	1.0701	881	
	119 633	60.83	67.59	66	42.62	66	1 131	4	96	37	1.2428	243	
	150 740	69.00	76.66	66	44.64	66	1 131	12	97	35	1.1179	876	
	121 420	51.97	57.74	66	44.64	66	1 131	....	......	..	1.0164	......	
	142 304	71.51	79.86	66	45.21	66	1 131	25	100	35	1.2714	1 175	
	57 091	31.47	34.96	66	46.65	66	1 131	21	97	36	1.0882	530	
	110 759	51.57	57.30	66	43.77	66	1 131	14	96	36	1.0544	908	
	192 451	73.53	81.70	66	43.77	66	599	16	99	35	1.1153	1 501	
Beta. 1896. Chief of Engineers' Rep., 1896, p. 3642.	803 341	57.03	63.37	84	56.26	86	1 162	2.6	96.9	35	1.018	868	Open runner 86 in. diameter, 8 blades, Rankin type, direct-connected to vertical, triple-expansion, condensing engine. Cylinders, 20.5 by 33 by 38 and 38 in., and 24-in. stroke.
	518 070	36.33	40.36	84	58.88	86	1 162	15.1	98.1	33	0.9775	2 847	
	526 920	37.05	41.16	84	60.27	86	1 162	34.6	97.5	34	0.9076	6 354	
	561 215	41.70	46.33	84	55.51	86	1 162	22.8	98.7	34	0.9736	4 988	
	614 483	46.60	51.78	84	57.38	86	1 162	36.4	98.1	35	0.9479	7 798	
	580 857	40.39	44.88	84	56.62	86	1 162	21.9	97.8	35	0.9673	4 850	
	584 359	48.04	53.37	84	54.76	86	1 162	17.4	99.4	32	1.019	3 872	
	583 400	42.50	47.22	84	55.51	86	1 162	29.0	97.5	33	0.9821	6 217	
	543 989	42.26	46.96	84	52.88	86	1 162	28.8	97.5	35	0.9819	6 327	
	577 564	43.79	48.66	84	54.01	86	1 162	21.5	97.5	35	0.9909	5 082	
	....	.....	.....	..	.....	..	.....	....	....	..	......	....	
	....	.....	.....	..	.....	..	.....	4.7	....	..	......	1 109	

SAND PUMP BUILT IN 1893
FOR THE DREDGE *ALPHA*

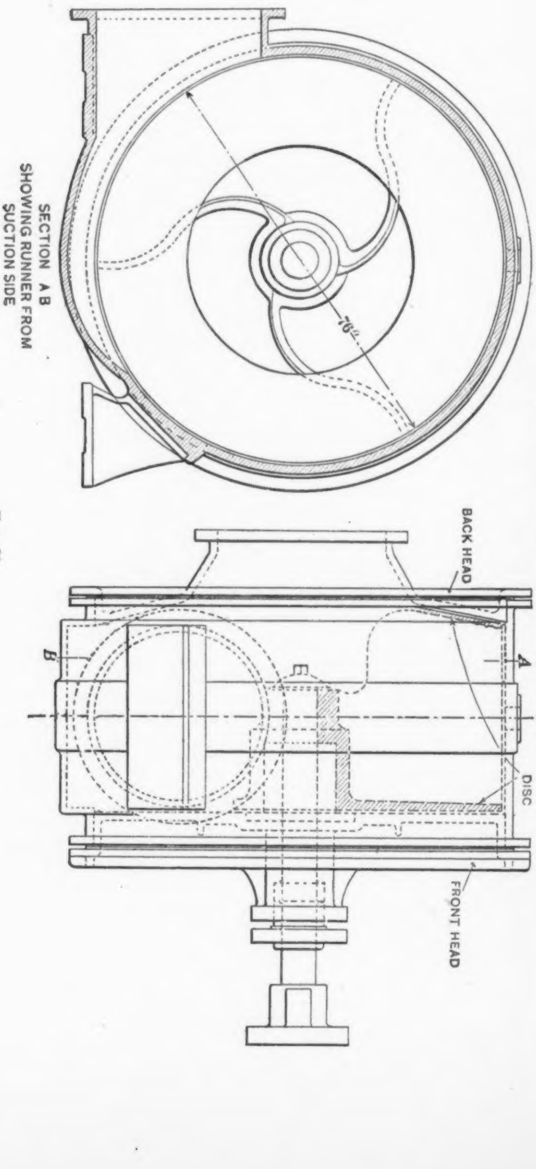


Fig. 20.

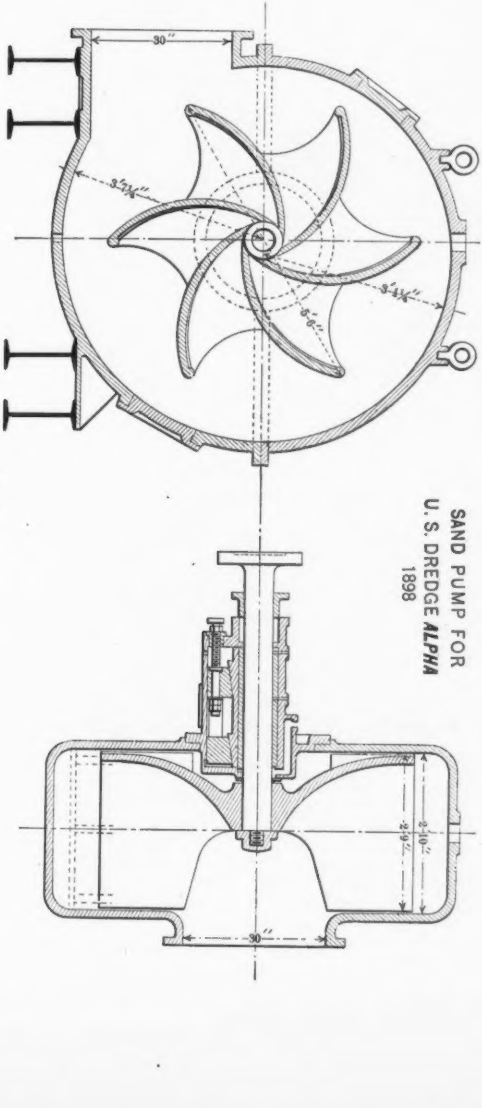
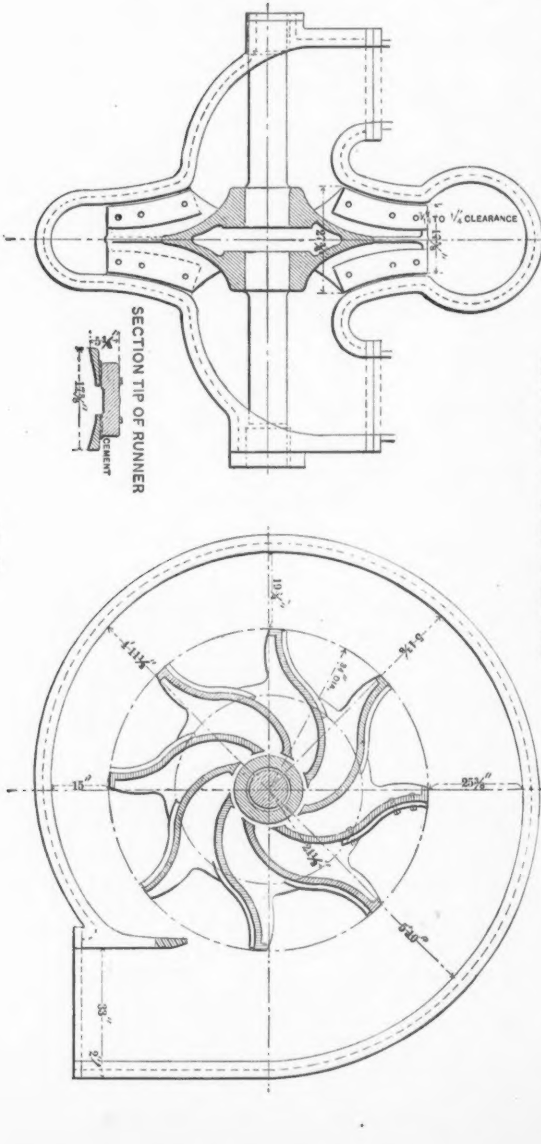
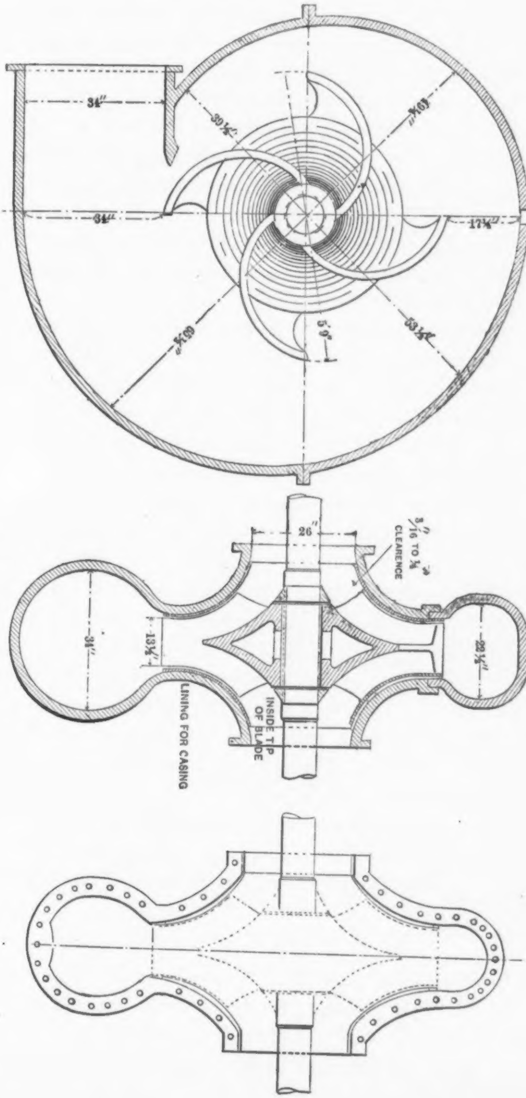


FIG. 21.



MAIN PUMP OF DREDGE *BETA* 1903

FIG. 22.



MAIN PUMP OF DREDGE *GAMMA*, 1902.

FIG. 23.

The instructions of the Committee on Dredging were to the effect that it was desired to obtain the efficiencies of the boilers, engines and sand pumps of each dredge. Tests were to be made by pumping water only, and at various speeds above and below the normal. In order to ascertain the effect of the form of the suction head, tests were to be made, when practicable, with the head removed. The loss of head, due to friction in discharge pipes and the effect of bends, was to be determined.

The plants were in good ordinary working condition, and no preparations were made for the tests except those necessary for attaching the apparatus used.

The machinery was operated by the regular crews and in the ordinary manner, except as to variation in speed; and it is believed that the results obtained are fair examples of those obtained in ordinary every-day operation. This feature was considered a desirable one, and should be borne in mind when comparing the measurements and methods with laboratory work.

The boiler tests will be referred to only briefly. They were made in accordance with the rules and practice adopted by the American Society of Mechanical Engineers, and, while interesting in themselves, the most valuable feature brought out was that the mean efficiency of thirty-six "Mississippi River" boilers tested was 9.10 lb. of water evaporated from and at 212° per lb. of combustible, as against 9.24 lb. with five Heine water-tube boilers. The "Mississippi River" type of boilers, it should be remembered, are return-flue, tubular, external-fired, with four or five flues of tubes from 11 to 13 in. in diameter. Those tested were from 44 to 48 in. in diameter and from 28 to 30 ft. long.

The engine tests made were to determine the relative steam consumption per indicated horse-power-hour of condensing and non-condensing, tandem, compound engines of approximately the same type.

Appliances for Measurements.

Pitot Tubes.—In determining the capacity of the centrifugal pumps, the very first problem presenting itself was the method of measuring the flow in a 32 to 34-in. pipe in which the velocity was from 14 to 25 ft. per sec. and under a head of from 18 to 30 ft. of water.

MAIN PUMP OF DREDGE *DELTA*, 1902.

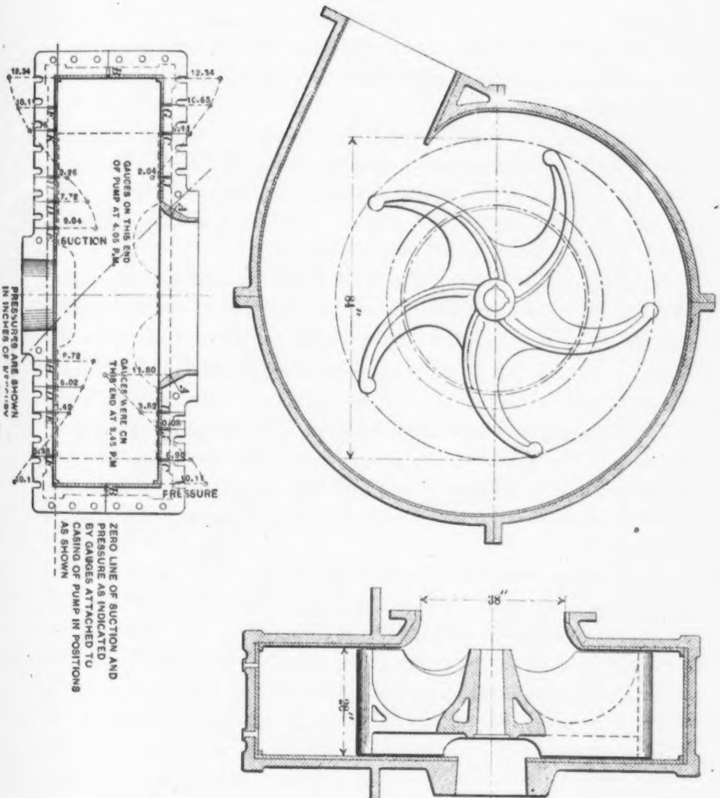


FIG. 24.

The instructions of the Committee recommended the use of Pitot tubes, and, after a careful study of the subject, the writer believes that no other method of measuring the velocities is as simple, inexpensive and practical. The publication of the paper,* by Messrs. Williams, Hubbell and Fenkell, on the flow of water in pipes, was most timely. A considerable portion of this paper and its discussion is devoted to the Pitot tube and the question of its merit as an accurate instrument for measuring the velocity of flowing water.

This accuracy seemed to be fully conceded with tubes properly constructed, and it remained to design a tube that could be inserted into the suction or discharge pipes readily, that would be strong enough to stand the rough usage to which it would be subjected, and still show accurate and reliable results.

In designing a tube for this work, it was thought that the theory that the impact point, when formed of a surface of revolution, will convert velocity head into static head, in accordance with the formula, $v = \sqrt{2\ g\ h}$, had been most thoroughly and conclusively demonstrated to be true in the discussion† by Mr. W. M. White and by some experiments‡ made by him. This point being accepted as true, it was necessary to design a tube in which the pressure point would give the true static pressure, or one with which there would be no suction action due to the current passing the pressure openings.

Nine tubes were constructed and experimented with, but the inherent defects of the design of all but Tubes Nos. 1, 3, 8, 9 and 10 were soon apparent and they were discarded. The writer admits that, had he been more familiar with the subject, it would not have been necessary to have made and experimented with certain forms which were tried, but as the mistakes of others are sometimes of value to those seeking information along lines unfamiliar to them, a brief description of all the tubes is given, with sketches of Tubes Nos. 1, 2, 3, 5, 6 and 8, in Figs. 25 and 26.

Tube No. 1 consists of two pieces of brass tubing, $\frac{1}{4}$ in., inside diameter, enclosed in an iron pipe 32.5 in. long, turned to $1\frac{15}{16}$ in., outside diameter. One of the small brass tubes is bent to a right

* *Transactions*, Am. Soc. C. E., Vol. XLVII, p. 1.

† *Transactions*, Am. Soc. C. E., Vol. XLVII, p. 292.

‡ Described in the *Journal of the Association of Engineering Societies*, August, 1901.

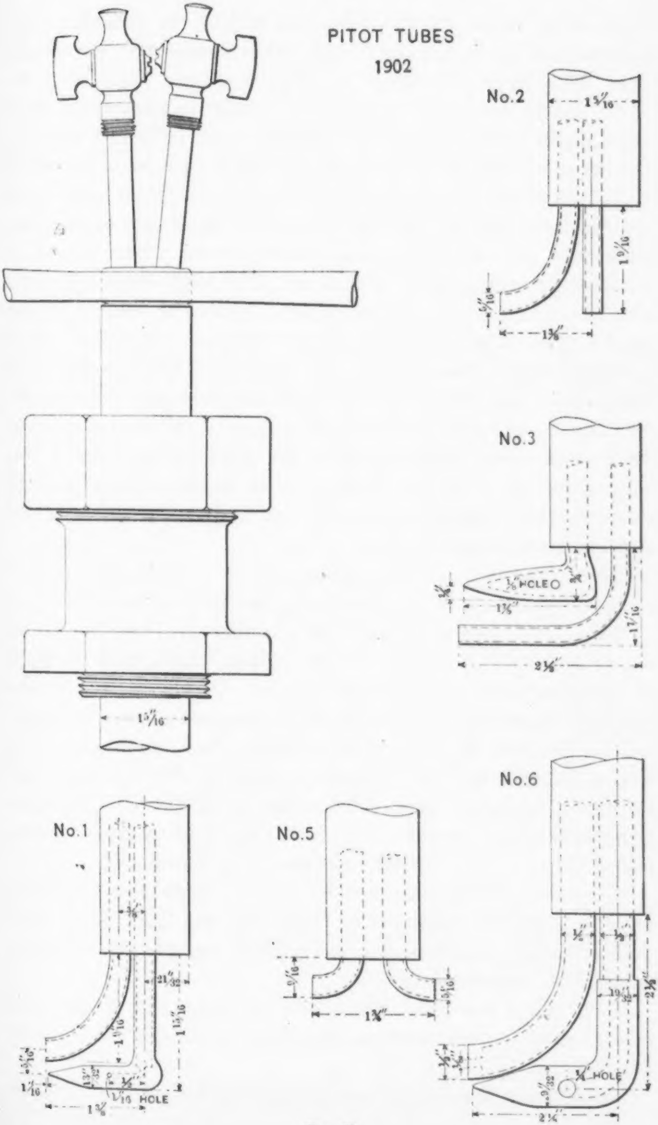


Fig. 25.

angle at its lower end and below the end of the enclosing pipe, and the plane of the opening is made truly parallel with the upright pipe. This forms the impact opening, or point. The other brass tube is brazed into a solid brass piece, circular in section, placed at right angles to the tube. The up-stream end is turned down to a sharp point, and its end is even with the impact point and below it. This brass point has a $\frac{1}{16}$-in. hole drilled in each side, connecting with the interior of the upright tubes. The upper ends of the brass tubes have $\frac{1}{4}$-in. air-cocks, which are connected to the gauges by $\frac{1}{4}$-in. rubber tubing about 4 ft. long. The small brass tubes are held in position in the enclosing pipe by lead or cement poured around them. The outside pipe slides through a stuffing-box, which is screwed into a hole tapped into the suction or discharge pipes with a $1\frac{1}{2}$-in. pipe tap. The top of the enclosing pipe has a handle set carefully at right angles with the plane of the impact opening. This arrangement permits placing the point of the tube at any point along the diameter of the pipe in which velocity is to be observed, and permits "traversing," or the determination of the velocity curve across the pipe.

The arrangement of the stuffing-box, the enclosing pipe handle and the connections to the gauges are common to all the tubes used.

Tube No. 2 has an impact point similar to Tube No. 1, but the static point is a simple, vertical, open-end tube, with the plane of the opening parallel with the current. Of all the tubes made, this form of pressure opening showed the greatest amount of suction action. In fact, the suction was greater than the impact force on the impact point, as was made evident by the fact that when the impact point was turned down stream it still showed a difference of pressure, due apparently to impact, about half as great as when facing the current. This tube was promptly abandoned.

Tube No. 3 is very similar to Tube No. 1, except that the impact point is below the static point. This tube and Tube No. 1 were used in making measurements, and a correction was applied to the readings, as mentioned later.

Tube No. 4 was Tube No. 2 with the lower end of the static tube plugged up and openings drilled in the side of the pipe. It was not used.

Tube No. 5 has impact and pressure points of similar form,

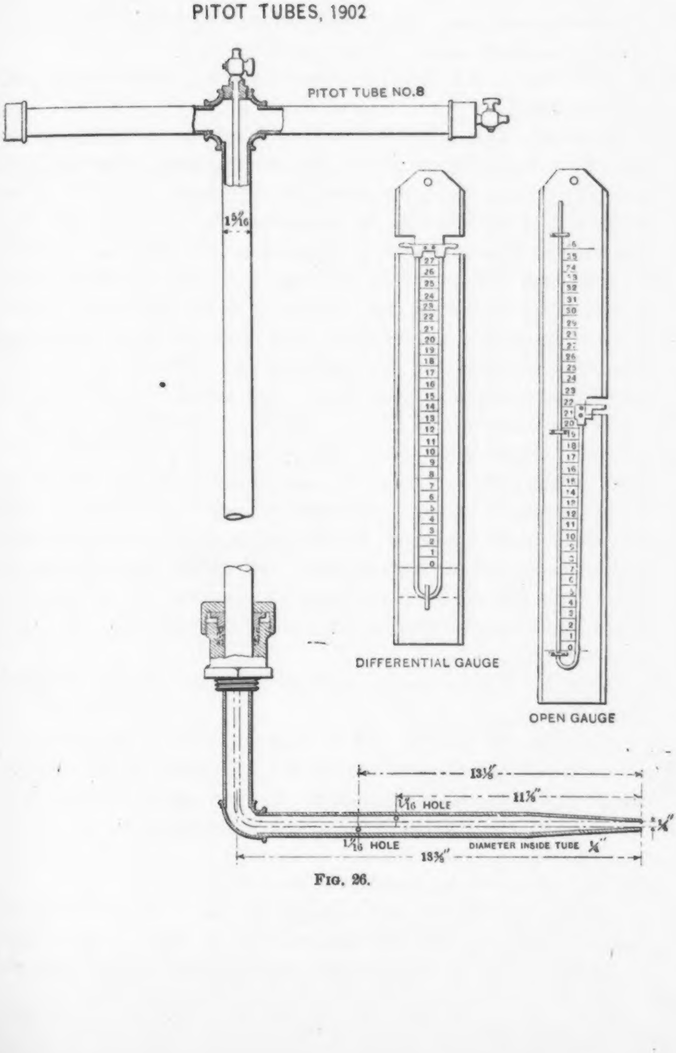

PITOT TUBES, 1902
PITOT TUBE NO.8
1 5/16
DIFFERENTIAL GAUGE
OPEN GAUGE
13 1/8"
11 7/8"
1/16 HOLE
1/16 HOLE
DIAMETER INSIDE TUBE 1/4"
13 3/8"
1/4"

FIG. 26.

but pointing in opposite directions. That there was a very considerable amount of suction with this form was very apparent, but the actual amount was not determined. It was not used.

Tube No. 6 is very similar to Tube No. 1, except that larger tubes were used, the impact point being filled with a plug having a hole $\frac{1}{8}$ in. in diameter. It was not used.

Tube No. 7 is a tube for measuring static pressure only, and was not used.

Tube No. 8 has a vertical outside pipe of the same size as the others, to permit the use of the same stuffing-boxes; otherwise, it is radically different from the forms just described, and, as the writer believes it to be of a form in which there is no suction action at the pressure openings, especial attention is invited to it.

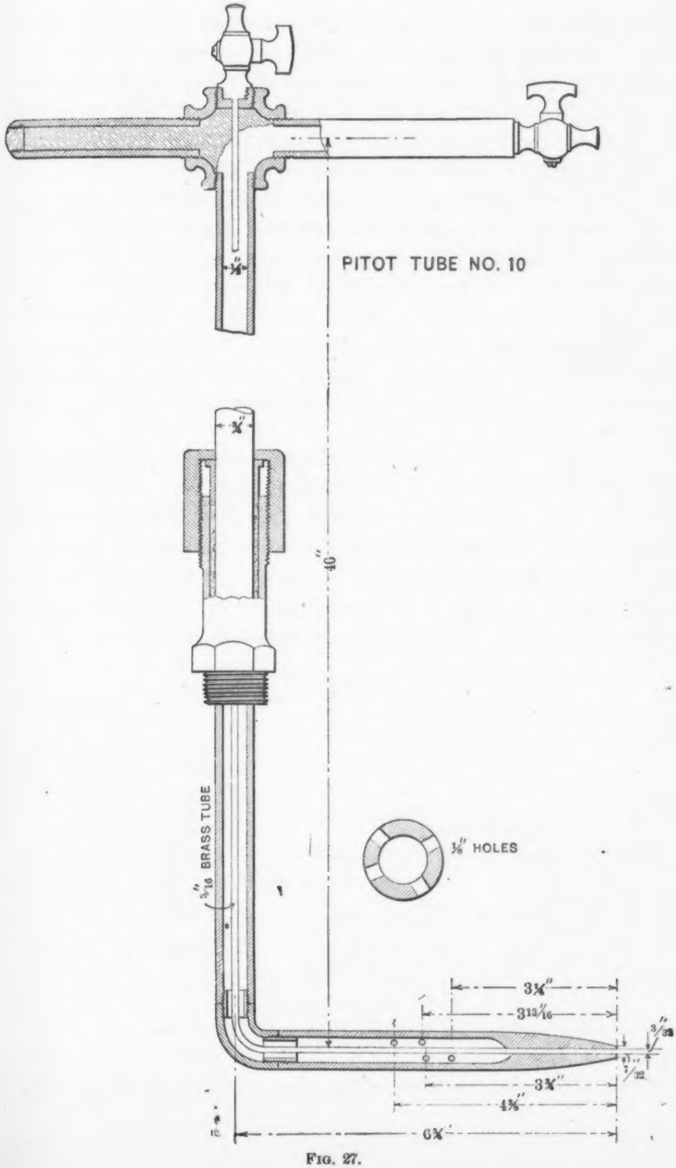
The lower end of the vertical pipe is joined at right angles to a 1-in. pipe about 18 in. long; the outer end of this pipe is drawn down to the size of a $\frac{1}{4}$-in. brass tube, which is brazed into it and forms the impact point. The tapering portion of the outside horizontal pipe is about 6 in. in length. The inside brass tube extends inside the outer pipe to the top, where it is provided with a $\frac{1}{4}$-in. air-cock. Three holes, about $\frac{1}{16}$ in. in diameter, are drilled in the sides of the outside horizontal pipe. These holes are not on the same diameter, and are in the straight portion of the pipe. Care was taken to drill them exactly normal to the surface of the pipe, which was ground true and smooth. These holes form the openings for determining the static pressure, the interior of the horizontal pipe being connected through the upright pipe and one handle to a $\frac{1}{4}$-in. air-cock.

Tube No. 9 is as nearly like Tube No. 8 as a skilled machinist could make it.

Tube No. 10, Fig. 26, has the characteristics of Nos. 8 and 9, except that it is somewhat smaller in all dimensions, and the horizontal pipe is considerably shorter. It was made as a result of all the experiments with other tubes, and is presented as the writer's idea of a cheap, practicable and accurate instrument for measuring the velocity of flowing water in pipes or conduits.

All the tubes, as well as the gauges used with them, and described later, were made by ordinary machinists in the shops on the dredges.

If the theory is accepted that velocity head will be converted



PITOT TUBE NO. 10
1/8"
3/4"
40"
3/16" BRASS TUBE
1/8" HOLES
3 1/4"
3 13/16
3/32"
7/32
3 3/4"
4 3/8"
6 3/4"

FIG. 27.

into static head by the impact point, as stated previously, and if the pressure openings give the true static pressure on the pipe, then the tube will have a coefficient of unity, in the formula $v = c\sqrt{2gh}$, where c is a coefficient and h is the observed difference of pressure shown by the static and impact points of the tube.

It is believed that Tubes Nos. 8, 9 and 10 have a coefficient of unity, and the following observations are presented in support of this belief: The most conclusive method of demonstrating the fact would be to rate the tubes under the same conditions under which they were used, but the difficulties of rating a tube in a 32-in. pipe having a velocity of flow of from 14 to 25 ft. per sec., and under a pressure of from 18 to 30 ft. of water can be readily understood, and no satisfactory methods suggested themselves to the writer as being practicable. The following observations and measurements, however, were made:

Tube No. 9 was rated in open running water having a velocity of about 3.5 ft. per sec. by comparing it with floats. In this case the tube was suspended in the river with the point about 12 in. below the surface and facing the current. The impact point and static openings were connected to opposite ends of an inverted U-tube of glass, from which the air could be partially exhausted in order to bring the water surface in the glass high enough to be read.

TABLE 31.

	Velocity, by float.	Velocity, by tube.
No. 1	3.316	3.420
" 2	3.284	3.279
" 3	3.517	3.393
" 4	3.419	3.358
" 5	3.405	3.502
" 6	3.212	3.228
" 7	3.362	3.354
" 8	3.332	3.218
Means	3.356	3.344

The floats were 1 by 2-in. wooden rods, 24 in. long, weighted to float vertically, and with about two-thirds of their length submerged. The time required to pass over a course 40 ft. long was

observed; the Pitot tube was about one-third the distance from the upper end of the course. Eighty floats were run and about 600 observations of tube readings made. In Table 31 the velocity given by the floats is a mean of 10 observations, and that given for the tube is the mean of about 75 readings.

The means show a coefficient of unity within about 0.33 per cent.

If Tubes Nos. 8 and 9 have coefficients of unity they should both give the same velocity in the same pipe at the same time.

To demonstrate this they were placed in the same discharge pipe, 50 ft. apart, and three sets of observations made with each tube simultaneously. The position of the tubes in reference to each other was then reversed and three sets of observations again made. The points of the tubes, in each case, were at the center of the pipe. The results are given in Table 32.

TABLE 32.

Velocity by Tube No. 8.	Velocity by Tube No. 9.	
25.370	24.500	
24.160	25.600	
25.770	25.140	
25.360	25.190	Reversed positions.
25.370	24.840	
25.550	25.020	
Means.... 25.263	25.048	

The means agree within about 0.8 per cent.

Somewhat later, Tubes Nos. 9 and 10 were compared in the same manner, with mean results showing a difference of 0.9 per cent.

That the accuracy of measurements by the tubes is not affected by pressure, was determined as follows:

Tube No. 8 was placed in the discharge pipe, on the second pontoon from the stern of the dredge, where the average static pressure was 17.5 in. of mercury; Tube No. 9 was placed in the discharge pipe on Pontoon No. 9, 350 ft. from Tube No. 8, and where the average pressure was 3.64 in. of mercury. Simultaneous readings were taken on gauges connected with each tube and at different points across the pipe. The mean velocity, as determined

by Tube No. 8, from 170 observations, was 22.321 ft. per sec. The mean, determined by Tube No. 9, was 22.351 ft. per sec., a difference of 0.1 per cent.

The pressure indicated by the static openings in Tube No. 9 was compared with piezometers in the sides of a 32-in. pipe, as follows:

Four holes were drilled and tapped for ¼-in. pipe at the four "quarters" of a 32-in. pipe, all being in the same vertical plane and care being taken to have the holes normal to the sides of the pipe. Ordinary ¼-in. air-cocks were screwed into these holes, their ends projecting inside the pipe slightly; these were then filed down carefully, to present a perfectly smooth surface flush with the inside of the pipe. It was thought that if there were any inaccuracies in the pressures indicated by the piezometers it would not be probable that the errors would be the same with each one; or, if the pressure indicated by each piezometer was the same, all would be correct. Each of the piezometers, in turn, was connected with every other one through a differential gauge, and in no case could three experienced observers detect any difference in pressure. Tube No. 9 was then inserted in the same vertical section, with the point of the tube at the center of the pipe. The pressure side of the tube was then connected in turn with each piezometer through a differential gauge, and in no case could any difference in pressure be detected. The pressures given by four piezometers, and the static, or pressure, side of the tube were exactly the same.

It is conceded that the foregoing observations do not demonstrate absolutely that the coefficients of Tubes Nos. 8 and 9 are unity, but, taken in connection with the discussion of the paper to which reference has been made, it is believed that they furnish sufficient evidence to warrant the assumption that their coefficient is unity, and the observations made with these tubes have been so considered in reducing results. Tubes Nos. 1 and 3 were compared with Tube No. 8 in the same manner that Tubes Nos. 8 and 9 were compared. The results show that Tube No. 1 has a coefficient of 0.930 and Tube No. 3 a coefficient of 0.8915, and these values have been used in reducing observations made with these tubes.

The Gauges.—Two forms of gauges, or manometers, were used in connection with the Pitot tubes and piezometers, and are shown in Fig. 26.

The differential gauges are simple U-shaped glass tubes, $\frac{1}{4}$ in. inside diameter, provided at each end with an attachment for connecting with a rubber tube. The whole was attached to a board having raised edges to protect the glass from injury. A paper scale, divided into inches and tenths, was fastened to the board behind the tubes, and both the scale and board were given a coat of varnish to prevent injury by water.

The open gauges are also U-shaped tubes, with one end longer than the other, and with an attachment for rubber tubes at one end only. The attachments for rubber tubes were of cast iron. The holes into which the glass tubes were inserted were counter-bored about $\frac{3}{32}$ in. larger than the glass, and this space was filled with Portland cement, which made a very satisfactory joint. The gauges were connected to piezometers or Pitot tubes with cloth-inserted, rubber tubing of $\frac{1}{4}$ in. inside diameter and not more than 4 or 5 ft. in length. The gauges were filled with mercury to such a height as was found necessary to indicate the pressure being measured. In one or two instances, where the pressure was very light, water was used in the gauges.

Considerable patience and ingenuity were required to remove all the air from the tubes and gauges above the mercury. It was found that a very small amount of air in the tubes would affect the readings very materially. The glass tubes were not calibrated, but a careful examination revealed no appreciable difference in the diameter. Commercial mercury was used, and its specific gravity was assumed to be 13.5. It is believed that the possible errors, due to differences of diameter in the tubes of the gauges, or the specific gravity of the mercury, are extremely small and well within the limits of observation.

Piezometers.—All piezometers were ordinary $\frac{1}{4}$-in., T-handled, air-cocks, screwed into holes tapped in the sides of the pipes and along their horizontal center. In wrought-iron pipes the inside end of the cock was made flush with the inside of the pipe, as nearly as could be done by measurement from the outside. The suction pipes of the pumps on the *Gamma, Delta, Epsilon* and *Zeta* are cast iron, about 1 in. thick, and in these the piezometers do not extend through the pipe.

Indicators.—The mechanical, or indicated, power developed by

the engines operating the pumps was obtained from cards taken by high-grade, steam-engine indicators, in the usual manner. Indicators were applied to each cylinder of the engines, and cards were taken from each simultaneously. The indicators were calibrated at the Tulane University, by Professor W. B. Gregory, and found to be practically correct. In determining the power from the cards they were worked out twice independently and checked by two computers.

Methods of Observation.—Measurements for determining the capacity and efficiency of the pumps and the drop in pressure along the discharge pipe were usually made at the same time. A Pitot tube was inserted in one suction pipe and in the discharge pipe at the same time. The tube in the discharge pipe was placed at considerable distance from the pump, usually in the first or second section of discharge pipe outside the dredge, in order to avoid the effects of the disturbance existing near the pump.

None of the dredges have suction pipes with straight pieces of any considerable length between elbows and bends of various sorts, and it was impracticable to insert the tubes in these pipes beyond the effect of these bends. For this reason the velocities obtained in the suction pipes were not used in computing the results. A piezometer was introduced in the suction pipe within 4 or 5 ft. of the flange on the pump, and in the discharge pipe at various convenient points along its length.

Figs. 28 to 33 show the general position of the pumps and arrangement of pipe lines on each dredge, also the points where Pitot tubes and piezometers were attached.

Pitot tubes were connected to differential gauges, and piezometers to open gauges, already described. When all was ready, the engines operating regularly, and when the air had been worked out of the tubes and gauges, a signal was given and the gauges were read and ten readings, comprising a set, were taken.

The mercury in the gauges connected with both the Pitot tubes and the piezometers, and in both suction and discharge pipes, fluctuated very rapidly and irregularly, and through a space of sometimes 2 or 3 in. At first glance, it seemed impossible to read the gauges with any degree of accuracy, but by watching them closely for several moments it was seen that there was an approximate mean position near which the mercury came to rest at short intervals.

DREDGE TESTS: ARRANGEMENT OF PIPE LINE ETC. ON THE DREDGE *BETA*, 1903.

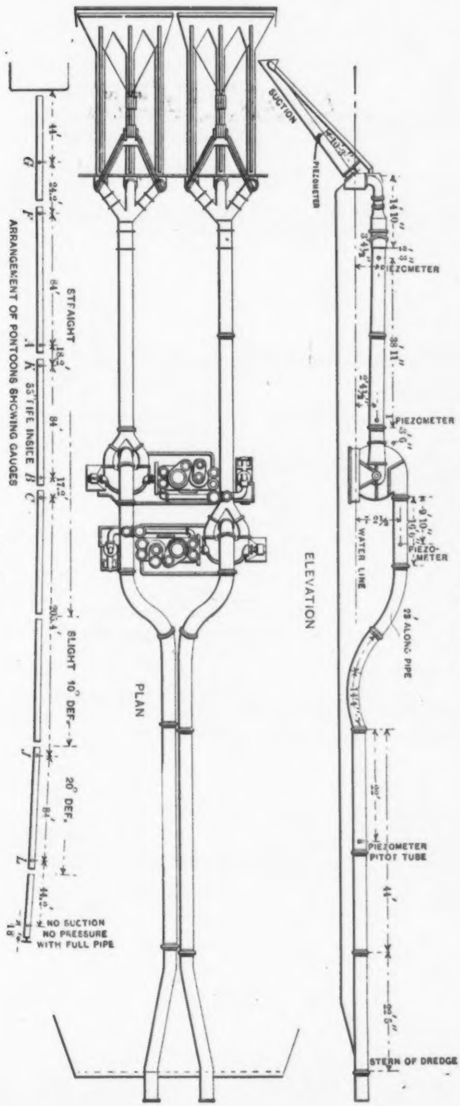
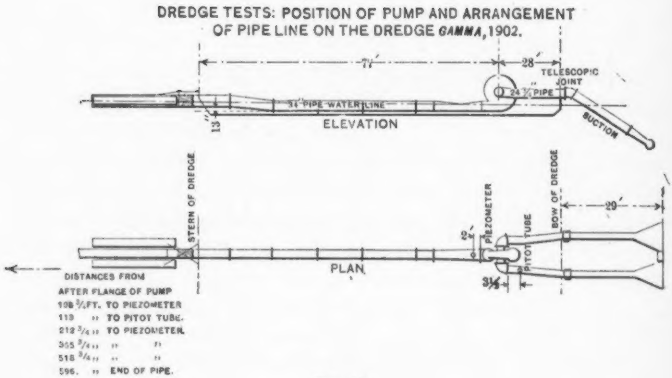
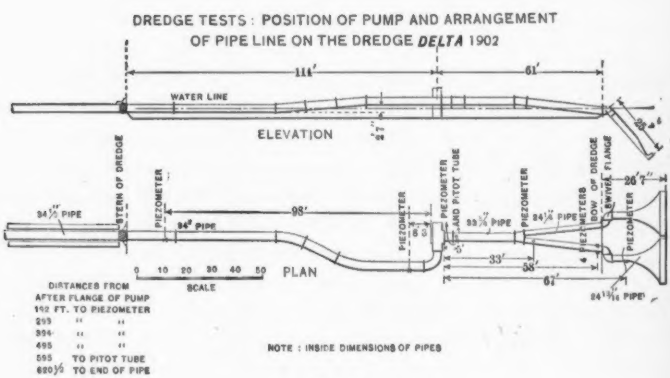


FIG. 28.



DREDGE TESTS: POSITION OF PUMP AND ARRANGEMENT OF PIPE LINE ON THE DREDGE GAMMA, 1902.
77′
28′
TELESCOPIC JOINT
24 ¾″ PIPE
34″ PIPE WATER LINE
ELEVATION
SUCTION
STERN OF DREDGE
PIEZOMETER
PITOT TUBE
BOW OF DREDGE
29′
PLAN
DISTANCES FROM
AFTER FLANGE OF PUMP
108 ¾ FT. TO PIEZOMETER
113 ″ TO PITOT TUBE.
212 ¾ ″ TO PIEZOMETER.
305 ¾ ″ ″ ″
518 ¾ ″ ″ ″
596. ″ END OF PIPE.

FIG. 29.



DREDGE TESTS: POSITION OF PUMP AND ARRANGEMENT OF PIPE LINE ON THE DREDGE DELTA 1902
114′
61′
WATER LINE
ELEVATION
STERN OF DREDGE
34 ½″ PIPE
PIEZOMETER
34″ PIPE
98′
PIEZOMETER
PIEZOMETER AND PITOT TUBE
33 ¾″ PIPE
PIEZOMETER
24 ¼″ PIPE
4 PIEZOMETERS
BOW OF DREDGE
SWIVEL FLANGE
PIEZOMETER
26′7″
33′
58′
67′
24 13/16″ PIPE
0 10 20 30 40 50
SCALE
PLAN
DISTANCES FROM
AFTER FLANGE OF PUMP
192 FT. TO PIEZOMETER
293 ″ ″
394 ″ ″
495 ″ ″
595 TO PITOT TUBE
620 ½ TO END OF PIPE
NOTE: INSIDE DIMENSIONS OF PIPES

FIG. 30.

DREDGE TESTS: POSITION OF PUMP AND ARRANGEMENT OF PIPE LINE ON THE DREDGES *EPSILON* AND *ZETA* 1902

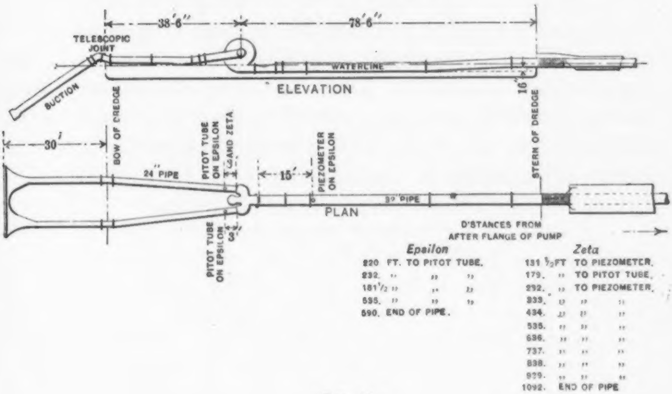


FIG. 31.

DREDGE TESTS: POSITION OF PUMP AND ARRANGEMENT OF PIPE LINE ON THE DREDGE *IOTA* 1902

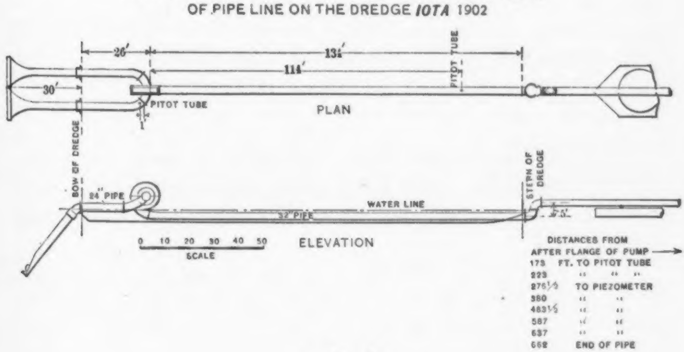


FIG. 32.

For this reason readings of the different gauges, during an observation for a set, were not taken exactly simultaneously or at regular intervals by each observer, but, after the signal was given each observer made the readings as rapidly as possible, observing the mean of the fluctuations as nearly as could be judged. As each leg of the gauge was read from five to ten times for any one set of observations, it is believed that the mean is correct within 0.1 in.

This method may be open to criticism, but, after making several hundred such observations under varying conditions, and noting how closely the mean readings agreed when the same conditions of speed of pump, etc., occurred, even though at different times, the writer has great faith in their accuracy.

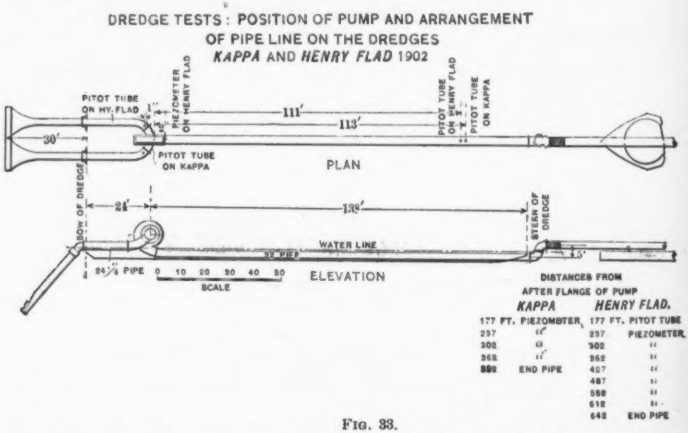


FIG. 33.

While the gauges were being read, indicator cards were taken, and the speed of the pump and readings of the steam gauge were recorded. The time required for completing a set of observations was from 5 to 10 minutes.

These observations were made at different speeds; the limiting speeds, on one hand, being so slow that experience in operation had shown it to be too slow for economic operation; on the other hand, the engines and pumps were run as fast as was thought expedient without risk of injury.

Reduction of Data.—To obtain the actual amount of power delivered to the pumps, it would have been very desirable to have

ascertained the frictional resistance of the engines alone at the different speeds. Efforts were made to do this, but the results were unsatisfactory, owing to the difficulty of obtaining satisfactory indicator cards. None of the automatic governors would hold the engines down to normal speed without load, and controlling the speed by throttling resulted in very poor cards.

From such cards as were obtained, and from a consideration of the type of engines, it was assumed that the power supplied to the pumps was 92% of the indicated horse-power. From the writer's rather intimate knowledge of the engines, he knows of no reason for believing that the efficiency of the engines varies greatly, and it is thought that the relative efficiencies are not far from correct, even if the assumed efficiency of the engines is in error. In each case the combined efficiency of pump and engine is also given.

In reducing the readings of gauges connected with piezometers, a correction was applied due to the height of the mercury, on the pressure side of the gauge, above or below the center of the pipes, or, in other words, all piezometer pressures were reduced to give pressures at the horizontal center of the pipes. In the few cases where the impact and static pressure points of Pitot tubes were connected to separate open gauges, the readings were reduced to give pressures at the point of the tube. Where, as was usually the case, the Pitot tube was attached to a differential gauge, there was no correction to be applied, due to the position of the gauge, as the same correction would apply to each side. There was applied, however, a correction due to the unbalanced column of water in one leg of the gauge, of a height equal to the difference between the heights of the mercury in the two legs of the gauge; *i. e.*, the difference of readings of the height of the mercury in the two legs of the gauge, which was apparently the height due to the pressure being observed, was reduced by the weight of an equal amount of water.

In obtaining suction and delivery head the suction head was obtained from readings of a piezometer in the suction pipe near the pump. Readings were taken on one suction pipe only, it being assumed that, on a double suction pump, the readings on each pipe would be the same. Some experiments on the *Epsilon* showed this to be practically true.

In determining the delivery, or discharge, head, it was feared

that a piezometer placed close to the pump might not give true pressures, owing to the violent disturbances in the flow. For this reason, piezometers were introduced in the straight pipe and some distance from the pump. The plotted line showing the fall in pressure in the pipe line, referred to later on, was extended back to the flange of the pump, and this pressure, corrected for any actual difference of elevation in the pipe between the pump and first gauge, was used for the delivery head.

In computing the amount of work done by the pump, the methods of determining head were the same as described under the discussion of the computations for the barge tests.

In the ordinary tests of the efficiency of centrifugal pumps, it is usual, as far as the writer knows, to measure the quantity of water pumped and the actual lift, and from these compute the work done. Unless to this quantity is added the head due to the friction in the pipes, the efficiency shown is that of the pump and pipes. With the pumps under consideration, the actual lift is very small, on the first five dredges practically nothing, while on the others it is probably never more than from 3 to 5% of the total head. Nearly all the work done, then, is expended in overcoming friction and creating velocity.

The writer can see no reason to believe that, with a given velocity of discharge, the efficiency of any pump would differ, whether the head pumped against was due to actual lift or friction in a long pipe, and for this reason believes that the results are comparable with those made in the ordinary way.

All measurements of velocity for determining capacity were taken at the center of the pipes, and it was necessary to determine the relation of center to mean velocity. This was done by "traversing," or measuring the velocity at intervals of 2 in. across the diameter of the pipe. This was done in each of the pipes, and at the point where velocity measurements were made for capacity. All were made on the vertical diameters, except in one instance on the *Iota*, where both vertical and horizontal traverses were made.

As all bends in the pipes, in the vicinity of the point of application of the Pitot tubes, which would affect the form of the velocity curve, are in a vertical plane, it is thought that the curve along a vertical diameter will indicate correct mean velocities.

MAIN PUMP OF DREDGE *EPSILON*, 1902

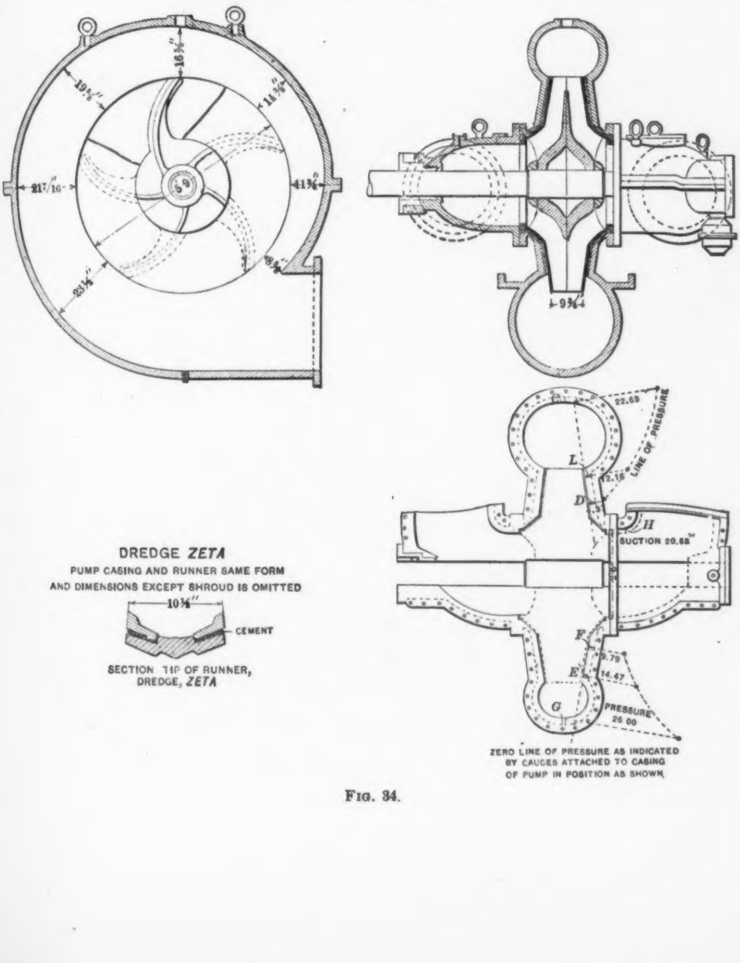


FIG. 34.

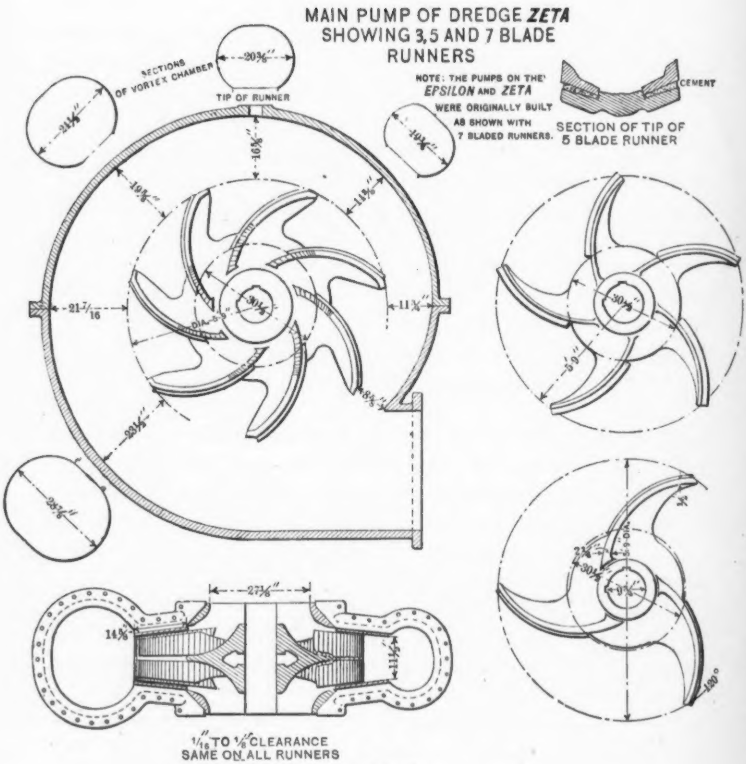

MAIN PUMP OF DREDGE ZETA
SHOWING 3,5 AND 7 BLADE
RUNNERS
NOTE: THE PUMPS ON THE EPSILON AND ZETA WERE ORIGINALLY BUILT AS SHOWN WITH 7 BLADED RUNNERS.
SECTIONS OF VORTEX CHAMBER
TIP OF RUNNER
CEMENT
SECTION OF TIP OF 5 BLADE RUNNER
1/16" TO 1/8" CLEARANCE
SAME ON ALL RUNNERS

FIG. 35.

MAIN PUMP OF DREDGE *IOTA*, 1902

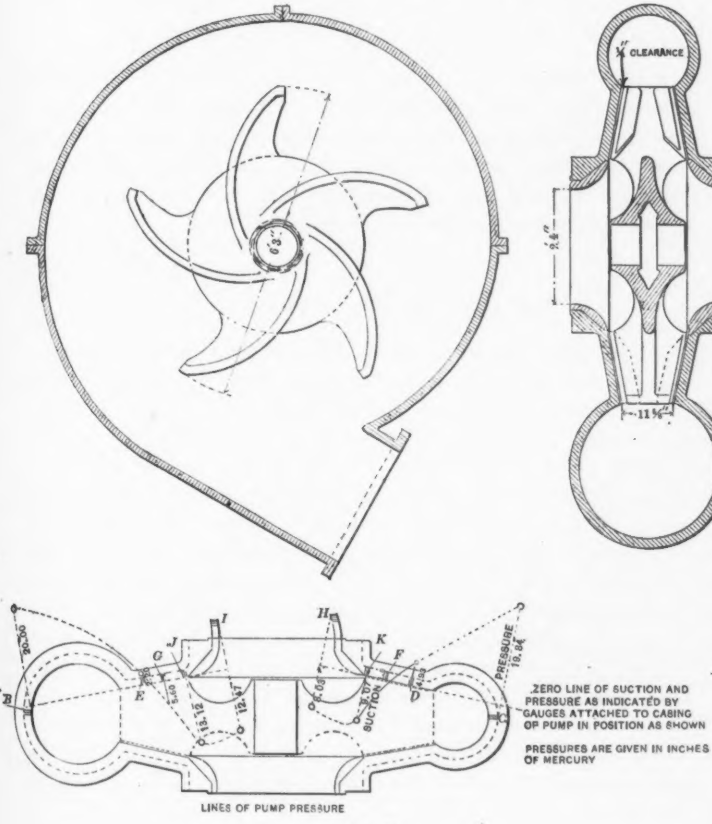


FIG. 36.

The results of the traverses were plotted and the mean velocity obtained by dividing the area of the pipe into ten concentric rings having equal areas and taking the mean of the velocities at the centers of these rings.

These velocity curves are not reproduced here but may be found in Appendix 1F, of the Report of the Chief of Engineers for 1903. Each plotted value is the mean of ten or more observations.

The mean value of $\frac{v\,m}{v\,c}$ for all the dredges is 0.8721, and varies from 0.8008 on the *Delta* to 0.9711 on the *Gamma*. This value does not seem to vary in proportion to the velocity entirely, but is probably affected by local conditions on each dredge. The value used for reducing center to mean velocities on each dredge was the value obtained on that individual dredge.

Description of Pumps.

Figs. 22, 23, 24, 34, 35, 36 and 37 show the form and characteristic dimensions of the pumps on each dredge, and Figs. 28 to 33 the general layout of pumps and pipe lines.

Dredge Beta.—The *Beta* has two independent pumps and engines, which are just alike. The one on the port side was tested. From the suction head or shoe, the water is conducted by three pipes, with a diameter of 19.5 in., which enter the bow of the dredge by radial bends and are joined in one suction pipe, 33.75 in. inside diameter, leading to the pump, where it is again divided and enters each side of the pump. The discharge pipe, 33.25 in. in diameter, is attached to the top of the pump, and, after leaving it, curves toward the center of the boat and downward. Beyond the dredge the pipes are supported on pontoons, and are submerged about one-third. The runner is an open one having 8 blades, of the Rankine form, or a reversed curve from the hub to the tip. The overhead discharge and form of runner are the principal characteristics of this pump.

Dredge Gamma.—The pump on the *Gamma* has a suction entrance on each side, the two suction pipes having an inside diameter of 24.75 in., leading to the shoe, or head. The inside area of this head is at all points somewhat greater than the area of the suction

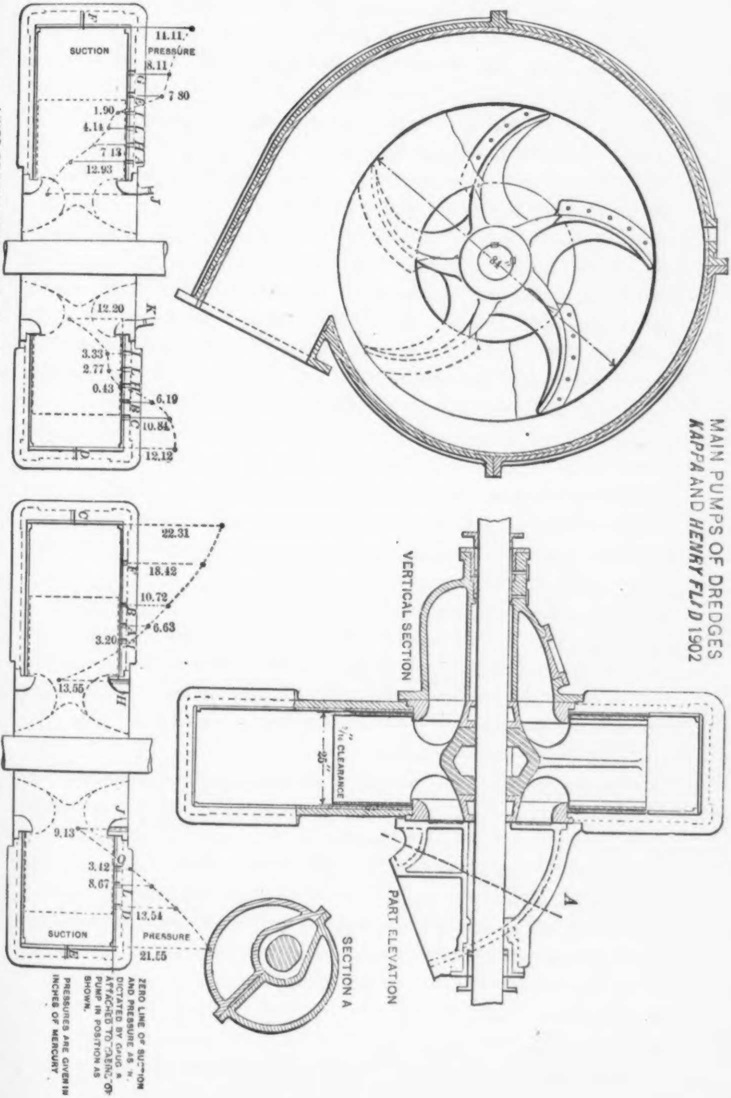

MAIN PUMPS OF DREDGES
KAPPA AND HENRY FLAD 1902
VERTICAL SECTION
PART ELEVATION
SECTION A
1/16" CLEARANCE
25"
SUCTION
PRESSURE
LINES OF PUMP PRESSURE ON DREDGE KAPPA
LINES OF PUMP PRESSURE ON DREDGE HENRY FLAD
ZERO LINE OF SUCTION AND PRESSURE AS INDICATED BY GAUGES ATTACHED TO CASING OF PUMP IN POSITION AS SHOWN.
PRESSURES ARE GIVEN IN INCHES OF MERCURY

Fig. 37.

pipes, and this is the case on all the dredges. The discharge pipe is 34 in., inside diameter, and the top is only a few inches above the water line. The top of the pipe is flattened down, a few feet from the pump, to just below the water line, to form a seal and prevent the entrance of air when priming the pump. Near the after end of the dredge the pipe rises about 13 in., and, outside the dredge, it is carried on pontoons. The pipe, outside or beyond the dredge, is submerged about one-half.

The pump has an open runner with 4 blades. The vortex chamber is oval in cross-section. The principal characteristic of the pump, in distinction to others, is the long, curved entrance on the suction side. In fact, this curve extends from the flange of the pump to the tip of the runner blades. The clearance between the runner blades and the casing in this pump, and in all others having open runners, is kept as small as possible, usually from $\frac{1}{8}$ to $\frac{3}{16}$ in. The amount of clearance is maintained by bolting edge-plates on the faces of the blades.

Dredge Delta.—This dredge has now the only single suction pump in use on the dredges under discussion. The case is rectangular, and the blades on the runner are rectangular in plan and much wider than in any of the other pumps.

The suction opening is 38 in. in diameter, tapering down to 33.75 in. about 4 ft. from the pump. This pipe branches into two 24.25-in. pipes leading to the shoe, or head. Just outside the dredge the suction pipe has two right-angle elbows, the vertical joint between them forming a swivel, about which the head revolves when being raised or lowered.

The discharge pipe is 34 in. in diameter inside the dredge, and 34.5 in. outside. The center of the discharge pipe just beyond the pump has about the same elevation as the center of the pump and drops down to about the water surface before leaving the dredge. Outside the dredge the pipe is submerged about one-half.

On the drawing of the horizontal section of the pump will be noted four plotted pressure lines. Holes were drilled into the casing along the horizontal center line, in the positions marked *A, B, C, D, E, F,* etc. These were tapped out and air-cocks inserted, which were connected with gauges, and the suction or pressure observed.

These observed pressures are plotted as shown, using the inside

lines of the two sides of the casing as zero lines, the suction being plotted inside the casing, and the pressure outside.

The pressures at *B*, on the ends of the casing, are plotted from the sides opposite them. These curves also appear on the drawings of some other pumps, and may be of interest in studying the action of the pumps, but do not enter into the present discussion.

Dredges Epsilon and Zeta.—The pumps on these two dredges were originally alike, and at present are alike as far as the casing of the pump and the arrangement of the pipe lines. The pumps have two suction pipes, 24 in., inside diameter, leading to the usual head. The discharge pipe is 32 in., nominal diameter, and occupies about the same position in reference to the water line as on the *Gamma.*

The sides of the casing are inclined toward each other, giving tapering blades on the runner. The vortex chamber is elliptical in cross-section. The runner on the *Epsilon* is of the shrouded, or enclosed type, while on the *Zeta* it is open. The drawing of the *Zeta's* pump shows also three runners having 3, 5 and 7 blades, respectively, which were tested under as nearly the same conditions as possible to determine the effect of the number of blades on the efficiency and capacity.

Dredge Iota.—The pump is of the same general form as those on the *Epsilon* and *Zeta,* and has an open runner with 5 blades. The runner is of larger diameter, and, necessarily, the casing is of greater size. The suction and discharge pipes are nominally of the same size, though varying somewhat at the point where measurements were taken. At the stern of the dredge there are two elbows, forming a reversed bend in a vertical direction. The flange between them forms a swivel joint, permitting the discharge to be turned at any angle with the axis of the dredge. These bends have a radius of 2.5 ft. on the center line. During the tests their vertical axis remained in the same plane.

After the dredging season of 1902, the runner on this pump was converted into one of the enclosed type by attaching a shroud, made of $\frac{3}{8}$-in. steel plates, to the edges of the blades, the same runner being used. The efficiency and capacity of the pump, under the changed conditions, were determined, and appear in Table 33.

Dredges Kappa and Flad.—These dredges have pumps made from

TABLE 33 —Data and Results

Name of Dredge.	Revolutions per minute.	Steam pressure in pounds.	Vacuum in inches of mercury.	Total indicated horse-power.	Suction Pipes.				Discharge Pipes.					Discharge in cubic feet per second.	Discharge in pounds per second.
					Inside diameter in inches.	Area in square feet.	Mean velocity in feet per second.	Velocity head in feet of water.	Inside diameter in inches.	Area in square feet.	Center velocity in feet per second.	Mean velocity in feet per second.	Velocity head in ft. of water.		
Beta.....	129	150	....	......	33¾	6.20	19.71	6.03	33¼	6.03	21.79	20.27	6.88	122.23	7639.38
	126	147.5	....	881.75	..	....	18.79	5.48	..	....	20.77	19.32	5.80	116.50	7281.25
	127	147.5	....	882.19	..	....	19.35	5.81	..	....	21.39	19.90	6.15	120.00	7500.00
	129	150	....	930.18	..	....	19.87	6.13	..	....	21.79	20.27	6.38	122.23	7639.38
	132	145	....	1018.30	..	....	20.23	6.35	..	....	22.36	20.80	6.72	125.42	7838.75
	130	142.5	....	962.97	..	....	19.87	6.13	..	....	21.97	20.43	6.48	123.19	7699.38
	136	......	....	1102.47	..	....	20.91	6.79	..	....	23.12	21.50	7.18	129.65	8103.13
	117	155	....	743.15	..	....	17.63	4.81	..	....	19.49	18.13	5.10	109.32	6832.50
	120	152	....	777.74	..	....	18.23	5.16	..	....	20.16	18.75	5.46	113.06	7066.25
Gamma..	142	138	22.0	297.47	24¾	6.682	12.982	2.62	34	6.305	14.170	13.760	2.94	86.757	5422.31
	154	147	22.0	356.91	..	....	13.680	2.90	..	....	14.930	14.499	3.27	91.416	5713.50
	160	139	22.0	407.93	..	....	14.395	3.22	..	....	15.710	15.256	3.62	96.189	6011.81
	167	145	22.5	457.61	..	....	15.007	3.50	..	....	16.379	15.905	3.93	100.281	6267.56
	153	147	22.5	351.74	..	....	13.600	2.87	..	....	14.843	14.414	3.23	90.880	5680.00
	154	142	22.5	352.94	..	....	13.870	2.99	..	....	15.138	14.701	3.36	92.690	5793.12
Delta	122	160	23.0	737.39	33¾	6.212	17.452	4.73	34½	6.492	20.854	16.700	4.34	108.416	6776.00
	122	162	23.0	737.39	..	....	16.965	4.47	..	....	20.272	16.234	4.10	105.391	6586.94
	124	165	23.0	784.15	..	....	17.784	4.92	..	....	21.250	17.017	4.50	110.474	6904.63
Epsilon..	158	144	....	587.50	24¼	6.414	17.554	4.79	32¼	5.673	22.522	19.847	6.13	112.592	7037.00
	165	139	....	680.70	..	....	18.482	5.31	..	....	23.715	20.897	6.78	118.549	7409.31
	166	141	....	687.92	..	....	18.356	5.23	..	....	23.533	20.737	6.69	117.641	7352.56
	168	123	....	712.67	..	....	18.755	5.46	..	...	24.064	21.205	6.99	120.296	7518.50
	171	140	....	765.97	..	....	19.088	5.66	..	....	24.492	21.582	7.24	122.485	7652.19
	181	133	....	874.69	..	....	19.513	5.91	..	....	25.036	22.062	7.53	125.158	7822.38
	181	133	....	867.41	..	....	19.441	5.76	..	....	24.944	21.981	7.51	124.698	7723.63
Zeta.....	178	120	....	592.08	24¼	6.414	13.701	2.92	32	5.585	19.397	15.735	3.85	87.880	5492.50
	180	130	....	622.08	..	....	13.727	2.93	..	....	19.434	15.765	3.86	88.048	5503.00
3-bladed	180	130	....	640.94	..	....	13.819	2.97	..	....	19.565	15.871	3.92	88.640	5540.00
runner	176	137	....	551.12	..	....	13.164	2.69	..	....	18.636	15.118	3.55	84.434	5277.13
	169	127	....	524.47	..	....	13.026	2.64	..	....	18.442	14.960	3.48	83.552	5222.00
Zeta.....	150	132	....	483.85	24¼	6.414	12.321	2.36	32	5.585	17.443	14.150	3.08	79.028	4939.25
	159	134	....	571.15	..	....	13.067	2.65	..	....	18.500	15.007	3.50	83.814	5238.38
5-bladed	170	126	....	690.40	..	....	14.234	3.15	..	....	20.150	16.347	4.15	91.298	5706.12
runner.	171	125	....	712.06	..	....	14.304	3.18	..	....	20.250	16.428	4.19	91.750	5734.37
	175	129	....	734.07	..	....	14.347	3.20	..	....	20.310	16.477	4.22	92.024	5751.50
Zeta.....	180	135	....	764.52	24¼	6.414	15.235	3.61	32	5.585	21.603	17.496	4.76	97.715	6107.19
	180	135	....	770.15	..	....	15.643	3.80	..	....	22.182	17.965	5.02	100.334	6270.87
7-bladed	168	125	....	639.47	..	....	14.769	3.39	..	....	20.942	16.961	4.47	94.727	5920.44
runner.	170	133	....	665.83	..	....	14.854	3.43	..	....	21.063	17.059	4.52	95.275	5954.69
	161	132	....	569.33	..	....	14.017	3.05	..	....	19.875	16.097	4.03	89.902	5618.88
	180	137	....	754.83	..	....	15.294	3.64	..	....	21.687	17.564	4.80	98.005	6130.94
	175	128	....	703.53	..	....	15.093	3.54	..	....	21.402	17.333	4.67	96.805	6050.31
Iota......	151	155	23.0	667.69	24	6.283	16.016	3.99	32$\frac{11}{16}$	5.828	18.600	17.181	4.59	100.131	6258.19
	165	150	24.8	817.83	..	....	16.622	4.29	..	....	19.400	17.920	4.99	104.438	6527.38
	165	150	25.0	817.83	..	....	16.862	4.42	..	....	19.680	18.179	5.14	105.947	6621.69
	165	150	25.0	817.83	..	....	16.751	4.36	..	....	19.550	18.059	5.07	105.248	6578.00
	168	146	25.2	867.54	..	....	17.393	4.70	..	....	20.300	18.751	5.47	109.281	6830.06
	168	146	25.2	867.54	..	....	17.393	4.70	..	....	20.300	18.751	5.47	109.281	6830.06
Iota	166	147	24	799.10	24	6.28	16.75	4.35	32$\frac{11}{16}$	5.83	19.37	18.10	5.01	105.52	6695.00
	168	155	24	823.49	..	....	19.85	6.12	..	....	22.65	21.30	7.05	124.18	7761.25
	168	153	24	800.82	..	....	19.45	5.86	..	....	22.20	20.90	6.77	121.85	7615.44
Kappa...	120	120	20.0	662.03	24¼	6.414	16.986	4.48	31⅞	5.541	22.436	19.663	6.01	108.953	6809.56
	123	146	20.3	744.80	..	....	17.893	4.98	..	....	23.634	20.713	6.67	114.771	7173.19
	126	153	20.0	793.49	..	....	18.130	5.11	..	....	23.947	20.987	6.85	116.289	7268.06
	126	160	20.0	797.19	..	....	18.114	5.10	..	....	23.925	20.968	6.84	116.184	7261.50
	127	165	19.2	817.70	..	....	18.508	5.32	..	....	24.446	21.424	7.13	118.710	7419.38
	129	165	20.0	844.85	..	....	18.552	5.35	..	....	24.505	21.476	7.17	118.998	7437.37
	132	160	20.0	885.95	..	....	18.808	5.50	..	....	24.843	21.772	7.37	120.639	7539.94
	133	165	20.0	926.34	..	....	19.079	5.66	..	....	25.200	22.085	7.55	122.373	7648.31
Hy. Flad.	115	152	17.0	537.35	24¼	6.414	12.869	2.57	32	5.585	18.742	14.780	3.40	82.546	5159.13
	115	139	15.0	521.53	..	....	12.869	2.57	..	....	18.742	14.780	3.40	82.546	5159.13
	120	145	14.5	590.61	..	....	14.586	3.31	..	....	21.243	16.752	4.36	93.560	5847.50
	126	123	20.0	634.98	..	....	14.796	3.40	..	....	21.549	16.993	4.49	94.906	5931.63
	129	116	21.0	645.58	..	....	14.767	3.39	..	....	21.505	16.959	4.47	94.716	5919.75
	129	117	21.0	644.31	..	....	14.896	3.45	..	....	21.694	17.108	4.55	95.548	5971.75
	131	137	14.0	782.68	..	....	16.665	4.32	..	....	24.270	19.139	5.69	106.891	6689.69
	128	137	18.0	701.29	..	....	15.249	3.62	..	....	22.208	17.513	4.77	97.810	6113.13

Note.—The efficiencies of pumps alone are based on an assumed efficiency of the engines of 92 per cent.

HEADS, IN FT. OF WATER.				Work done in foot-pounds per second.	Percentage of efficiency of pump and engine.	Percentage of efficiency of pump.	Diameter of runner in inches.	Peripheral velocity in feet per second.	$\frac{\sqrt{2gh}}{V_p}$	Length of suction pipe in feet.	Length of discharge pipe in feet.	REMARKS.
Suction.	Delivery.	Velocity.	Total.									
10.72	24.58	0.35	35.65	272343.90	....	....	84	47.2811	......	110.0	745.8	600-ft. pontoons.
10.59	23.89	0.32	34.80	253387.50	52.2	56.7	..	46.1815	......	....	....	
10.53	24.14	0.34	35.01	262575.00	54.1	58.8	..	46.5477	......	....	....	
10.62	24.76	0.25	35.63	272191.11	53.2	57.8	..	47.2811	......	....	....	
11.36	27.01	0.37	38.74	303673.18	54.2	58.8	..	48.3806	......	....	....	
11.21	26.51	0.35	38.07	293115.40	55.3	60.1	..	47.6477	......	....	....	
12.42	28.77	0.39	41.58	336928.15	55.5	60.3	..	49.8467	......	....	....	
9.59	20.66	0.29	30.54	208664.55	51.5	55.9	..	42.8828	......	....	....	
9.65	20.37	0.30	30.32	214248.71	50.7	55.1	..	43.9824	......	....	....	
7.09	12.54	0.32	19.95	108175.08	66.1	71.4	69	42.7519	0.8379	57.0	596.0	500-ft. pontoons.
7.90	13.90	0.37	22.17	126668.29	64.5	69.7	..	46.3648	0.8145	....	....	
8.75	15.36	0.40	24.51	147349.46	65.6	70.8	..	48.1712	0.8242	....	....	
9.29	16.31	0.43	26.03	163144.65	64.8	70.0	..	50.2787	0.8138	....	....	
8.24	13.80	0.36	22.40	127232.00	65.7	70.6	..	46.0637	0.8241	....	....	Suction head rem'v'd
8.32	13.90	0.37	22.59	130866.58	67.4	72.8	..	46.3648	0.8221	....	....	" " "
18.86	15.32	—0.39	33.79	228961.04	56.4	60.9	84	44.7154	1.0436	87.6	620.5	500-ft. pontoons.
19.72	15.52	—0.37	34.87	229686.59	56.6	61.1	..	44.7154	1.0591	....	....	
19.17	15.80	—0.42	34.55	238554.96	55.3	59.7	..	45.4485	1.0372	....	....	
9.85	22.78	1.34	33.97	239046.89	73.9	79.8	69	47.5691	0.9826	68.5	590.0	500-ft. pontoons.
10.91	24.97	1.47	37.35	276737.72	73.9	79.8	..	49.6766	0.9866	....	....	
10.24	25.05	1.46	36.75	270206.58	71.4	77.1	..	49.9776	0.9728	....	....	
11.50	25.65	1.53	38.68	290815.58	74.1	80.0	..	50.5798	0.9862	....	....	
11.95	26.60	1.58	40.13	307082.38	72.8	78.6	..	51.4830	0.9869	....	....	
12.49	28.86	1.62	42.97	336127.67	69.8	75.4	..	54.4937	0.9647	....	....	
12.46	28.70	1.75	42.91	331420.96	69.4	74.9	..	54.4937	0.9641	....	....	
8.22	33.86	0.93	43.01	236232.43	72.5	78.8	69	53.590	......	68.5	1092.0	1 000-ft. pontoons.
7.99	34.65	0.93	43.57	239765.71	70.1	76.3	..	54.192	......	....	....	
7.58	35.02	0.95	43.55	241267.00	68.4	74.3	..	54.192	......	....	....	
7.24	32.14	0.86	40.24	214351.71	70.0	76.1	..	53.068	......	....	....	
7.08	31.58	0.84	39.50	206269.00	71.5	77.7	..	50.880	......	....	....	
5.85	29.81	0.72	36.38	179689.91	67.5	72.9	69	45.1605	......	68.5	1092.0	1 000-ft. pontoons.
6.47	33.75	0.85	41.07	215140.26	68.4	73.9	..	47.8700	......	....	....	
7.72	39.60	1.00	48.32	275719.72	72.6	78.4	..	51.1819	......	....	....	
7.85	42.29	1.01	50.15	287578.65	73.4	79.3	..	51.4830	......	....	....	
8.28	40.16	1.02	49.46	284469.19	70.4	76.0	..	52.6873	......	....	....	
6.90	40.73	1.15	48.78	297908.1	70.85	77.0	69	54.192	......	68.5	1092.0	1 000-ft. pontoons.
7.13	41.83	1.22	50.18	314672.4	74.28	80.7	..	54.192	......	....	....	
6.13	37.35	1.08	44.56	263814.2	75.01	81.5	..	50.759	......	....	....	
6.28	38.22	1.09	45.59	271474.3	74.14	80.6	..	51.1819	......	....	....	
5.73	34.46	0.98	41.17	231329.3	73.87	80.3	..	47.4115	......	....	....	
6.86	41.03	1.10	49.05	300721.2	70.79	76.9	..	54.192	......	....	....	
6.56	39.17	1.13	46.86	283517.5	73.27	79.6	..	52.566	......	....	....	
9.74	26.55	0.60	36.89	230864.63	62.9	72.4	75	49.4147	1.0181	56.0	662.0	
10.71	31.75	0.70	43.16	281721.82	62.6	72.2	..	53.9963	1.0086	....	....	
10.68	31.85	0.72	43.25	286388.08	63.7	73.3	..	53.9963	1.0090	....	....	
10.77	31.80	0.71	43.28	284795.84	63.3	73.0	..	53.9963	1.0099	....	....	500-ft. pontoons.
10.79	33.80	0.77	45.36	309711.52	64.9	74.0	..	54.978	1.0092	....	....	Open runner.
11.22	33.70	0.77	45.69	312065.44	65.4	74.6	..	54.978	1.0137	....	....	
12.35	30.91	0.66	43.92	289652.40	65.9	71.6	75	54.324	......	56.0	662.0	
12.48	31.16	0.93	44.57	345918.91	76.4	83.0	..	54.978	......	....	....	Shrouded runner.
12.41	30.96	0.91	44.28	337211.57	76.1	82.7	..	54.978	......	....	....	
10.70	26.19	1.53	38.42	261623.29	71.8	77.5	84	43.9826	1.1302	54.0	392.0	240-ft pontoons.
11.22	28.07	1.69	40.98	293957.32	71.7	77.4	..	45.0820	1.1388	....	....	
11.72	28.44	1.74	41.90	304531.71	69.7	75.3	..	46.1815	1.1241	....	....	
11.72	28.44	1.74	41.90	304256.85	69.3	74.8	..	46.1815	1.1241	....	....	
11.90	28.81	1.81	42.52	315472.93	70.1	75.7	..	46.5480	1.1235	....	....	
12.23	28.82	1.82	42.87	318840.05	68.6	74.1	..	47.2811	1.1106	....	....	
12.75	29.05	1.87	43.67	329269.18	67.5	72.9	..	48.3806	1.0954	....	....	
12.94	29.35	1.89	44.18	337902.33	66.3	71.6	..	48.7472	1.0936	....	....	
9.19	26.91	0.83	36.93	190526.67	64.4	69.5	84	42.1498	1.1563	54.0	642.0	480-ft. pontoons.
9.19	26.91	0 83	36.93	190526.67	66.4	71.7	..	42.1498	1.1563	....	....	
9.78	29.25	1.05	40.08	234367.80	72.1	77.9	..	43.9826	1.1544	....	....	
10.78	30.32	1.09	42.19	250255.47	71.6	77.3	..	46.1815	1.1280	....	....	
11.30	29.87	1.08	42.25	250109.44	70.4	76.0	..	47.2811	1.1026	....	....	
11.30	30.24	1.10	42.64	254635.42	71.8	77.5	..	47.2811	1.1076	....	....	
11.64	35.00	1.37	48.01	321172.02	74.6	80.6	..	48.0141	1.1574	....	....	
11.14	31.95	1.15	44.24	270444.87	70.1	75.7	..	46.9146	1.1370	....	....	

the same drawings. The casings are rectangular in section. The runners are enclosed, or shrouded, have 5 blades, and are larger in diameter than any except the *Delta*. The discharge and suction pipes, and the arrangement are the same as on the *Iota*.

Results.—Table 33 gives the data and results of the tests just described, and it is thought that the column headings explain their significance.

Fig. 38 shows the work done and the efficiency of engines and pumps at the various peripheral velocities covered by the experiments.

Table 34 shows the extreme range in peripheral velocity with each pump, with the efficiencies and capacities corresponding to these speeds.

TABLE 34.

DREDGE.	Range in peripheral velocity.	Percentage.	Mean efficiencies at extremes of speed. Engine and pump.	Percentage.	Mean capacity, in thousands of foot-pounds per second, at extreme speeds.	Percentage.
Beta	42.88 to 49.84	16	51.5 to 55.5	+4.0	208.7 to 336.9	61
Gamma	42.75 to 50.27	17	66.1 to 64.8	—1.3	108.2 to 163.1	50
Delta	44.71 to 45.44	1	56.5 to 55.3	—1.2	229.0 to 238.5	4
Epsilon	47.56 to 54.49	14	73.9 to 69.6	—4.3	239.0 to 333.7	39
Zeta (3-blade)	50.88 to 54.19	6	71.5 to 69.2	—2.3	206.3 to 240.4	11
Zeta (5-blade)	45.16 to 52.68	17	67.5 to 70.4	+2.9	179.7 to 284.5	57
Zeta (7-blade)	47.41 to 54.19	14	73.9 to 72.0	—1.9	231.3 to 304.4	32
Iota	49.41 to 54.98	11	62.9 to 65.1	+2.2	230.8 to 310.8	34
Kappa	43.98 to 48.74	10	71.8 to 66.3	—5.5	261.6 to 337.9	29
Henry Flad	42.15 to 48.01	14	65.4 to 74.6	+9.2	190.5 to 321.2	68
Extreme	42.15 to 54.98	30	55.3 to 74.6	19.03	108.2 to 337.9	212

It will be noted, on Fig. 38, that the efficiencies at the extreme speeds do not cover the highest efficiencies on the *Gamma, Zeta* or *Epsilon,* though they do on the *Beta, Iota, Kappa* and *Flad.*

On the *Gamma, Delta, Epsilon, Zeta* (with 3- and 7- bladed runners) and *Kappa* the efficiencies have decreased with higher speeds, while with the *Beta,* the *Zeta's* 5-bladed runner, the *Iota* and the *Flad* the efficiencies have increased. If the efficiency at the lowest speed on the *Flad* be omitted, there is very little variation in the efficiencies of any one pump at the speeds covered. The

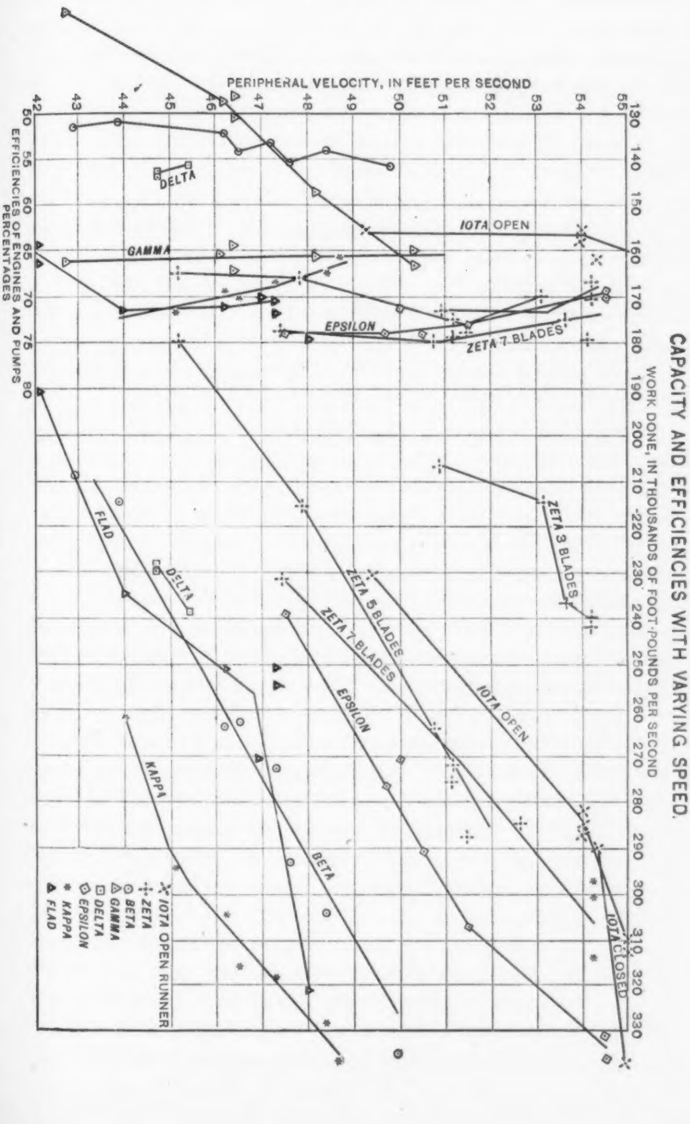

CAPACITY AND EFFICIENCIES WITH VARYING SPEED.
WORK DONE, IN THOUSANDS OF FOOT-POUNDS PER SECOND
PERIPHERAL VELOCITY, IN FEET PER SECOND
EFFICIENCIES OF ENGINES AND PUMPS
PERCENTAGES
IOTA OPEN
GAMMA
DELTA
EPSILON
ZETA 7 BLADES
ZETA 3 BLADES
ZETA 5 BLADES
ZETA 7 BLADES
EPSILON
IOTA OPEN
DELTA
FLAD
BETA
KAPPA
IOTA CLOSED
IOTA OPEN RUNNER
ZETA
BETA
GAMMA
DELTA
EPSILON
KAPPA
FLAD

FIG. 38.

work done, or capacity of the pump, with one exception only, has increased to a very marked degree to the maximum speed, with no indication that the speed for maximum capacity has been reached.

On the *Beta* the capacity was increased 61% with an increase of speed of 16% and an increase of 4% in efficiency.

On the *Gamma* the capacity was increased 50% with an increase of speed of 17% and a difference of only 1.3% in efficiency, on the *Epsilon* an increase of speed of 14% has increased the capacity 39%, with a decrease of only 4.3% in efficiency; on the *Zeta,* with a 5-bladed runner, an increase of speed of 17% has increased the capacity 57%, with an increase of less than 3% in efficiency, while, with the 7-bladed runner, an increase of speed of 14% has been followed by an increase of 32% in capacity; on the *Iota, Kappa* and *Flad* an increase of speed of 11, 10 and 14% has increased the capacities 34, 29 and 68%, respectively.

On the whole series of experiments, leaving out only the *Beta* and *Delta,* whose efficiencies are so much lower than the others as to be quite marked, the whole range of speed, from about 42 to 55 ft. per sec., or 30% increase, has been followed by an extreme range of efficiencies of from 64.8% to 73.9%, or only about 10%, while the range in capacities is more than 200% of the lowest.

Evidently, then, regarding mechanical efficiency alone, speed, within reasonable limits, makes very little difference, but, to obtain the maximum output from the plant, the pumps should be run at as high speed as is practicable. This feature, when the pump is used for dredging, is important in more than one way: At a high speed the velocity through the pipes is higher, and as velocity, in a hydraulic dredge, is the only vehicle of transportation, it would seem that, within certain limits, the proportion of sand to water, or sand-carrying capacity, will increase with the velocity, and not only a larger volume of a mixture of sand and water will be moved in a given time, but the proportion of sand in this volume will be greater.

The writer realizes that as soon as he ventures to draw conclusions and express opinions he lays himself open to criticism, and it has been the desire to present the facts of observations and results and allow those who are interested to draw their own conclusions. In order to invite discussion, certain comparisons will

be made, and opinions expressed as to the causes of differences in results.

From Table 33 and Fig. 38 are found the mean efficiencies of engines and pumps at what may be called normal speeds, as in Table 35.

TABLE 35.

Dredge.	Speed, in revolutions per minute.	Mean efficiency of engine and pump.	Mean capacity, in feet-pounds per second.
Beta	122 to 136	55.0	311 000
Gamma	153 to 167	65.6	146 000
Delta	122 to 124	56.1	235 000
Epsilon	165 to 180	71.9	308 000
Zeta (3-blade)	169 to 180	70.5	220 000
Zeta (5-blade)	165 to 180	71.8	275 000
Zeta (7-blade)	165 to 180	73.5	279 000
Iota	165 to 168	64.0	297 000
Iota (shrouded)	166 to 168	72.8	315 000
Kappa	129 to 131	68.3	322 500
Henry Flad	129 to 131	70.0	287 500

In the preparation of Table 35 there is room for a wide difference of opinion as to what speeds should be included as "normal," and on this decision will also depend the given normal efficiencies and capacities. The speeds given are those used in ordinary operation, except for the *Epsilon* and *Zeta,* which might possibly be narrowed down to speeds between 170 and 180, but the relative results would not vary greatly.

On the *Kappa* and *Flad,* in explanation of the limiting speeds, they are limited to 129 and 131 because, ordinarily, the dredges are operated at from 130 to 135 rev. per min. The efficiency of the *Flad* is taken from the plotted curve of efficiencies, rather than from the single high efficiency given for the higher speed.

Number of Blades on the Runner.—The most advantageous number of blades that an impeller should have has been the subject of considerable discussion and of equal difference of opinion. To throw some light on this subject three runners were tested in the pump on the *Zeta,* having 3, 5 and 7 blades, respectively.

By testing the different runners in the same pump under the same conditions, much more reliable comparisons can be made than

if they had been tested in different pumps, and the writer presents these tests with considerable confidence in their reliability and in the conclusions to be drawn from them. All were open runners and all had about the same clearance with the casing; *i. e.*, from $\frac{1}{8}$ to $\frac{3}{16}$ in.

Referring to Table 35, note that the mean efficiency was 70.5, 71.8 and 73.5% with the 3, 5 and 7 blades, respectively, an extreme variation of only 3%; or, practically, within these limits, the number of blades has very little effect on efficiency.

Referring to capacity, however, that of the 3 blades is 220 000 ft.-lb. per sec., as against 275 000 and 279 000 with 5 and 7 blades; an increase of 25% with 5 blades and of nearly 27% with a runner having 7 blades. The same arguments for high speed would seem to apply to runners with the larger number of blades. The fact that the difference between the runners with 5 and 7 blades, both in efficiency and capacity, is small, would seem to indicate that 7 blades, if made of the form and size of those under consideration, is about the limiting number. It would be difficult, if not impossible, to make a runner with more blades, of sufficient strength to withstand the rough work of dredging, without contracting seriously the available area for entrance at the hub of the pump.

Comparison of Barge Tests of 1896-98 and Tests of 1902.

It must be borne in mind that all the barge tests were made, primarily, to determine the capacity of the pumps while handling sand, and, usually, to determine the maximum capacity. With the exception of the tests on the *Alpha,* all these tests were made to ascertain whether the contract requirements as to capacity had been complied with. The pumps were operated at their maximum speed, which was considerably higher than the possible working speed, and usually considerably higher than the speeds reached in the tests of 1902.

The time occupied in any one test was very short, usually less than 2 min., while one set of observations in 1902 covered from 5 to 10 min., and the whole series covered a period of several hours; fortunately, however, the barge tests cover quite a large number of observations on each dredge at practically the same speeds, and

it is believed that the mean results represent very closely the actual average conditions.

Unfortunately, owing to the fact that existing conditions were not the same during the different tests, the results of the barge tests and those of 1902 cannot be compared rigidly.

In some instances the pumps had been remodeled, in others the length of discharge pipe used was not the same, or the speed of the pumps was widely different.

The following few comparisons are submitted:

The *Gamma* has the same pump and engine as supplied originally, the only changes that have been made are those necessary to keep it in repair. The length of discharge pipe was widely different in the two tests, so that velocity and head cannot be compared, but the mean efficiency of the pump and engine with the barge tests is 67.6% as against 65.8% in 1902, a difference of less than 2 per cent.

On the *Delta* the speeds during the two tests vary widely, and the efficiencies in 1902 are much lower.

On the *Epsilon* the pump has been rebuilt.

The *Zeta*, with the 7-bladed runner, in 1902 gives the best comparison with the barge tests. In this instance conditions were very nearly the same. The pump was the same, except for some variations due to wear; the length of the discharge pipe was nearly the same, and nearly the same speeds were covered.

The mean velocity in the discharge pipe, at 180 rev. per min., in 1902, was 17.67 ft. per sec., while the mean velocity at 180 and 181 rev. in the barge tests was 17.15; the mean total heads, in feet of water, at these speeds was 49.33 and 46.65, respectively. The mean efficiency of the pump and engine, with the barge tests was 72.24, while with the tests of 1902 it was 73.17.

These comparisons are not entirely conclusive, but when it is remembered that the tests were several years apart, made by entirely different observers and by radically different methods, they tend, in the writer's opinion, to give additional confidence in the results of both series of tests.

Comparison of Pumps.

Nearly all the pumps tested differ in more than one particular in design, and it is difficult to point with assurance to any one

feature as being the one which affects efficiency to the greatest extent.

The pumps on the *Epsilon* and *Zeta*, with 5 blades, are identical, with the exception that the runner on the former is closed, or shrouded, and that on the latter is not. Reference to Table 33 and Fig. 38, shows that the mean efficiency is almost identical with each, but the capacity is about 12% greater with the shrouded runner. This added capacity, owing to the runner being enclosed, is to be expected, as there is no spilling over the edges, or "slip."

The greatest advantage of the closed runner, however, lies in the decreased wear of the edges of the blades and casing, which is a very serious matter on the pumps handling sand or gravel. The amount of this wear in the pumps on the *Gamma, Epsilon* and *Zeta* has been described in a paper* by the writer. Briefly, it was found that on the *Epsilon,* after a little more than 1 000 hours' dredging, the casing, which was of good cast iron, originally with a thickness of about 2 in., had been worn entirely through. The edges of the runner blades were worn off nearly 1 in. This excessive clearance, of course, would decrease the efficiency very materially.

It will be noted that the efficiency of the *Gamma* is from 5 to 6% lower that that of the *Epsilon* or *Zeta,* while the capacity is less than half of either. As noted above, the principal characteristic of the pump is that its sides are curved from the suction opening to the tips of the blades of the runner and that the runner has 4 blades.

From the foregoing comparison, it is evident that this curve does not possess any advantage, and it is certainly much more expensive to make and maintain in repair. From experiments made on the *Zeta,* it is evident that the number of blades does not affect the efficiency, though it does affect the capacity.

The efficiency of the pumps on the *Beta* is about 10% less than those on the *Gamma,* and from 15 to 18% less than those on the other dredges, except the *Delta.* The principal characteristics of the pump are shown on Fig. 22, and it will be noted that the principal differences between it and the others lie in the overhead discharge and the form of runner. The writer does not venture an opinion as to which feature, if either, causes the low efficiency.

The *Delta* has the only single suction pump now in use on these

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* *Journal of the Association of Engineering Societies*, May, 1900.

dredges, though both pumps used on the *Alpha* had single suction openings.

Fig. 24 shows the characteristics and dimensions of the *Delta's* pump, and it will be noted that the blades of the runner are much wider than on the other pumps. The writer cannot see any reason why the latter feature should affect the efficiency, though, at the same peripheral velocity, it should increase the capacity, and that this is true seems to be indicated by the results shown in Fig. 38. It is perhaps unfortunate that the observations with this pump do not cover a wider range of speed, but the writer has confidence in the results obtained, and there is no indication, from the results obtained with the other pumps, that the efficiency would have been increased materially with higher speeds.

This statement may not be true for this pump, as it is noted that in the barge tests an average speed of 151 rev. gave an average efficiency of 65.1% for the engine and pump. Taking the mean of the efficiencies for this pump as obtained in 1897 and 1902 as 60.5%, it is still lower than any other except the *Beta*. The average efficiency of the engine and Edwards and Morris pumps on the *Alpha,* which were both single suction pumps, was 60.4 and 61.3%, respectively. From these results the conclusion would seem to be inevitable that the decreased efficiency is due to the single suction opening and the consequent unbalanced thrust on the shaft, which must be taken up in a thrust bearing.

The writer is aware that certain manufacturers of centrifugal pumps object strongly to building them with double suction openings, but in the light of the foregoing tests and a practical experience in the operation of both types, the writer favors very strongly a pump having a suction opening on each side.

The *Iota,* with an open runner, does not compare very favorably with the *Zeta* in efficiency, though the pumps are of the same general form, differing only in size. The writer can see no reason for this, except that the clearance between the edges of the runner blades and the casing may have been somewhat greater on the *Iota* than on the *Zeta.* The results with the closed runner corroborate the conclusions reached by comparing the *Epsilon* and *Zeta.* In this case the addition of the shroud has been followed by an increase of efficiency of more than 8% and an increase of 6% in capacity.

It will be noted, in comparing the *Epsilon* and *Iota,* with shrouded runners which are of the same general form except as to size, that the efficiencies do not vary greatly.

The *Kappa* and *Flad* have pumps just alike, and are the latest built for use on this work. They were made from detailed drawings prepared in the office of the Commission. The pumps on the dredges mentioned previously were furnished by the contractors who built the dredges, and under specifications requiring that they should have a certain given capacity.

The characteristics of the pumps are: Enclosed runners, with blades rectangular in plan and of considerably greater width than the others; the vortex chamber rectangular in cross-section, having the same width as the runner. The casing is lined throughout with renewable liners of very simple shape.

Apparently, they have an efficiency slightly lower than the *Epsilon, Zeta* and *Iota,* with the tapering blades and curved vortex chambers, but this very slight loss in efficiency is very much more than counterbalanced by the cheaper form of construction and greater ease and less expense in making repairs due to wear alone. For use in dredging, the writer believes that they possess great advantages over any of the others mentioned, though it is possible that for pumping water alone a pump designed on finer theoretic lines might have a slightly higher efficiency.

Comparing the two pumps, it will be noted that the efficiencies are very nearly the same, differing by only 1.7%; the capacity of the *Kappa,* however, was 10% greater than that of the *Flad,* and the difference was even greater than that at the lower speeds.

The writer ventures the following opinion as to the cause of this difference. The *Kappa* had 240 ft. of discharge pipe beyond the dredge and (Table 33) at 129 rev. created a mean velocity of about 21.5 ft. per sec. against a total head of 42.9 ft., while the *Flad,* with 480 ft. of discharge pipe, at the same speed, created a velocity of only about 17 ft. per sec. though the total head was only about 0.5 ft. less than on the *Kappa.* It seems to the writer that this indicates that a centrifugal pump is capable of doing more work by creating velocity than by overcoming a head due either to an actual lift or to friction in the pipe. It is possible that this difference would not have been as marked at higher peripheral velocities.

An inspection of the results of the barge tests of the *Alpha,* where different lengths of discharge pipe were used with the same pump, seems to corroborate the observations on the *Kappa* and *Flad.* With the Edwards pump, with 604 ft. of discharge pipe, the efficiency was 55.7%, while with 1 059 ft. it was 52.1 per cent. The work done with the longer pipe is 10% less than with the short pipe, though the speed of the pump was much greater in the last instance.

The Loss of Head Due to Friction in Pipes.

An inspection of Table 33 shows that the delivery head is a very large proportion of the total head against which the pump was working, amounting on the *Gamma, Delta, Epsilon* and *Zeta,* with discharge pipes running nearly horizontal from the pumps, to from 55 to 60% with 500 ft. of floating pipe and from 70 to 75% with 1 000 ft. of floating pipe. On the *Iota, Kappa* and *Flad,* this proportion is from 60 to 75%, but on these dredges the delivery head includes an actual lift of about 5 ft. at the stern of the dredge, as well as the loss by friction. The drop in pressure along the pipe line was determined by inserting piezometers at various points, as already described, and by simultaneous readings on gauges connected with them.

These readings, corrected for the position of the gauges above or below the center of the pipes, are plotted in Plate XXXVII. The location of the piezometers and the arrangement of pipes have been referred to in Figs. 28 to 33.

On the diagrams showing the drop in pressure on all the pipes except the *Beta,* the loss includes the loss at the joints connecting the several sections of pipe. These connecting joints, on the first six dredges, are short pieces of rubber hose which slip over the ends of the adjacent sections of pipe. On the pipe belonging to the *Kappa* and *Flad* the connections are ball and socket joints, secured so as to allow a deflection of about 20° on either side of the center line.

On the diagram of the loss on the *Beta's* pipe, the drop between Gauges F and A and K and B represents the loss in the straight pipe alone. The distance between the gauges was 84 ft. in each case. The pipe is of wrought iron, ¼ in. thick, 33 in. inside diameter.

It is made up in rings about 5 ft. in length, and all rivets are countersunk on the inside. The lap of the rings is in the direction of the current, and the pipe is perfectly smooth and bright on the inside, due to the action of the sand pumped through it.

The loss of head between these gauges is expressed numerically in Table 36.

TABLE 36.

Mean velocity, in feet, per second.	Loss, in inches of mercury.		Mean loss, in feet of water for 84 feet of pipe.	$f = \frac{h}{v^2} \frac{d\,2g}{L}$
	F to A.	K to B.		
18.0	2.25	2.10	2.446	0.0146
19.2	2.64	2.08	2.655	0.0139
19.4	3.08	2.27	3.009	0.0154
20.8	2.79	2.46	2.953	0.0132
21.4	3.10	2.70	3.262	0.0138
21.7	3.13	2.46	3.144	0.0129

The results are not conclusive, as it is realized that the number of observations is limited, but they are presented as a possible small addition to the knowledge concerning the flow of water through iron pipes.

On the *Beta, Gamma, Delta* and *Zeta* the drop in pressure from the stern of the dredge to the end of the pipe line is fairly uniform, though the lines on the *Beta* are not as smooth and uniform as on the others. On the *Gamma* and *Delta* the drop in pressure between the last gauge inside the dredge to the first one on the pontoons is not in line with the ones on the pontoon line, owing to the complications of an actual lift of 13 in. on the *Gamma* and a drop on the *Delta,* and also a change in the diameter of the pipe.

The *Iota, Kappa* and *Flad* show interesting indications of the effect of short, abrupt bends on the loss of head. On each of these dredges there is a reversed bend at the stern of the dredge, the effect of which is shown in the drop between the last gauge on the dredge and the first one on the pontoons. This drop, on the *Iota,* is from 9.5 to 12 in. of mercury; this amount may be partly accounted for by an absolute lift of 5 ft., or 4.4 in. of mercury, and a drop of about 2.8 in., due to the horizontal distance between

gauges, leaving a loss of head, due to the bends, of from 2.3 to 4.8 in. of mercury, or from about 10 to 16% of the total delivery head.

On the *Kappa,* with a shorter discharge pipe, the effect of the short bends is more marked, the net loss being 7.1 in., or 25% of the total delivery head. On the *Flad* this loss amounts to about 2.4 in., or a little less than 10 per cent.

There is also shown the increase in the suction due to the reversed curves in the suction pipe of the *Delta.* In this case, the pipe on each side of the curves was about on the same level, as the bends are horizontal. The difference, then, of about 7 in. of mercury, or more than 50% of the total suction head, is nearly all due to the bends. It does not seem to require any further argument as to the undesirability of short bends in the pipes.

The upper line on the diagram of the loss of pressure on the *Flad* shows the additional load caused by deflecting the pipes, at each joint, to the limit of their throw, about 20°, indicating that the loss due to slight bends, all in the same direction, is not great.

It will be noted, on the diagrams showing the loss of pressure on the *Iota, Kappa* and *Flad,* that the point of zero pressure is at the last gauge, or about 30 ft. from the end of the pipe, instead of at the end of the pipe, as would be expected. This is also true on the *Beta* at a gauge which happened to be 18 ft. from the end. On the first three the discharge pipe is entirely above water; on the latter the discharge pipe is submerged about one-third.

An explanation of this fact is not attempted by the writer at present, but that it was a fact on all four dredges is beyond doubt, as the observations were tested in various ways.

When the piezometer was connected to the ordinary mercury gauge it showed no pressure or suction; occasionally the mercury would fluctuate from 0.05 in. above zero to an equal distance below. The mercury was then poured out of the gauge and it was filled with water to the height of the piezometer, and it still showed no pressure and no suction, though the water in the glass would fluctuate occasionally 0.5 in. above or below the zero.

The gauges were then removed and the air-cock unscrewed from the hole in the pipe. This hole is 0.5 in. in diameter; but, although it was on the horizontal center of a 32-in. pipe flowing entirely full and at a mean velocity of from 14 to 21 ft. per sec., no water came

out except occasionally a few drops, which seemed to be caught on the down-stream edge of the hole and thrown out. This observation was made on each of the four dredges mentioned; how far from the end of the pipe the condition of no pressure extended was not determined. This was only true when the pipes were flowing entirely full at the ends; when, on the *Iota,* the speed of the pump was reduced to such an extent that the water filled the discharge pipe at the end to within 4 or 5 in. of the top, then the water in the gauge attached to the piezometer rose to approximately the height of the water in the pipe, as in an open channel.

The Effective Cross-section of the Discharge Pipe, and the Proportion of Sand Pumped.

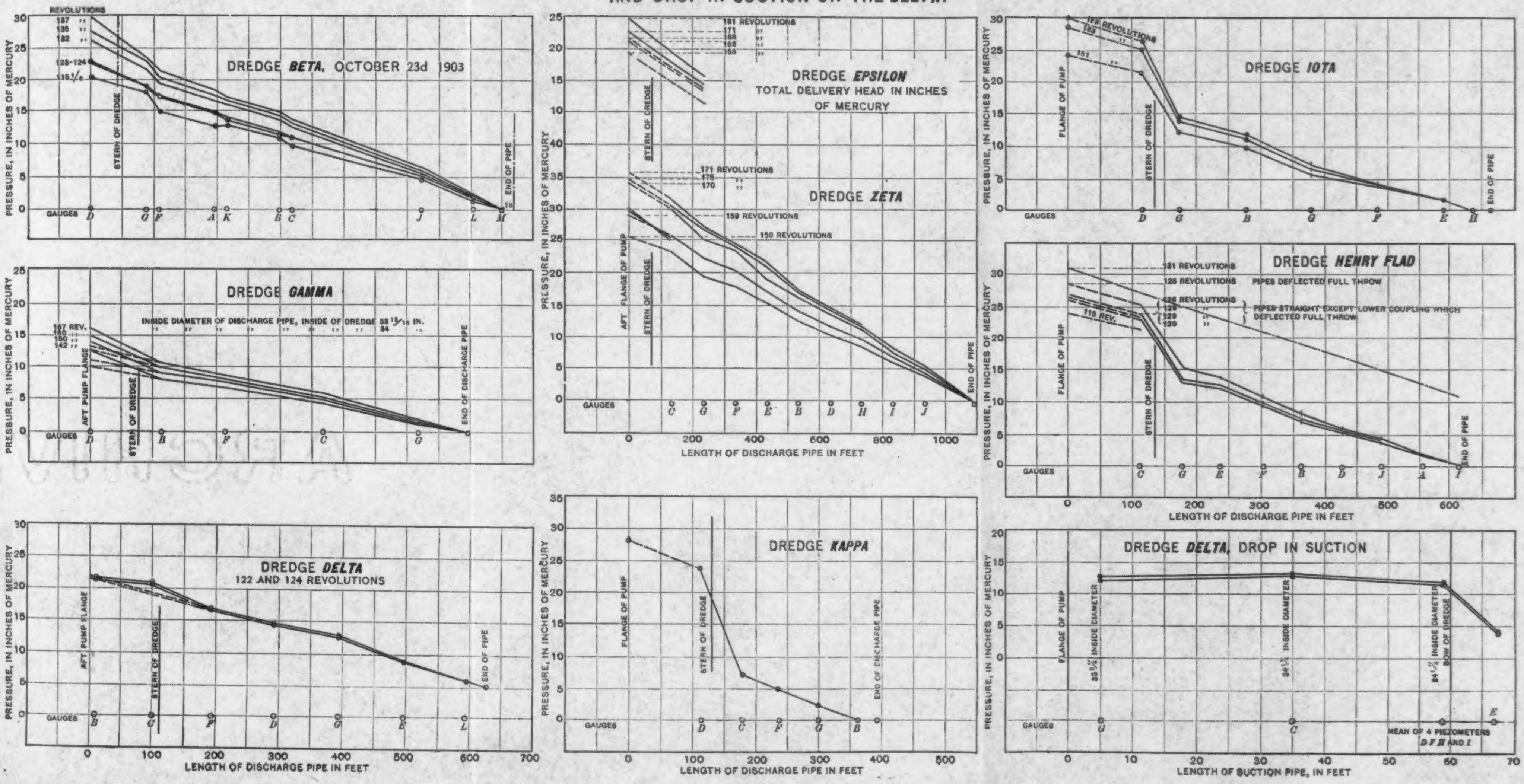
Paragraph 7 of the resolution of the Committee instructed that the velocity of discharge should be measured at several points in the cross-section of the pipe, while pumping sand, to determine the effective cross-section.

During the progress of the experiments already described, the writer was not successful in determining the velocity of the discharge while pumping sand, but was successful in determining the effective cross-section, and several determinations were made of the proportion of sand carried.

The apparatus devised was as follows: A piece of 1-in. pipe, about 4 ft. long, was fitted to go through one of the stuffing-boxes, already described as used with the Pitot tubes; the lower end of the pipe was bent to a right angle to face the current; the upper end of the pipe was fitted with two elbows, so arranged as to turn the opening downward; between the elbows was a gate-valve for shutting off the flow of water. The fittings on the top of the pipe formed a handle by which it could be manipulated. The stuffing-box permitted the lower end of the pipe to be placed at any point along the vertical diameter at the point of application.

The lower end of the pipe being made to face the current, and the valve being opened, the water would flow into the lower end and out at the upper end, as the vertical height of the pipe was much less than the head on the pipe at that point, and it was assumed that this stream of water would carry the same proportion

DROP IN PRESSURE AT VARIOUS LENGTHS OF DISCHARGE AND DROP IN SUCTION ON THE *DELTA*.



of sand as was being carried in the discharge pipe at the point of the tube.

The water and sand issuing from the pipe was caught in iron buckets and tin cans, and the proportional part of sand measured. No attempt was made to determine the sediment or mud in suspension, but only that portion of the material which settled to the bottom of the receptacle at once, or say within a minute. These measurements were made at intervals of 2 in. along the diameter. Three sets of traverses were made on the *Delta,* while dredging at Peters Crossing, and eight on the *Kappa,* in the chute of President's Island; and Tables 37 and 38 show the results.

The evidence that the whole cross-section of the discharge pipe is effective is quite conclusive, as in no case was there any evidence that any sand was resting on the bottom of the pipe, as the small pipe was shoved down to the bottom in every set of observations.

The indicated proportion of sand carried varies widely, and, from the nature of the work, it must be true that the actual proportion of sand being carried varies constantly. It cannot be assumed that sand flows in a constant, uniform stream into the suction head, and, in fact, it is very well known that it does not do so. It will be necessary, therefore, to take a large number of observations to determine with accuracy what proportion of sand is carried.

The results of the three sets of observations on the *Delta* have been plotted and the mean of the eight sets also plotted. Two of the sets on the *Delta* were taken while dredging down stream; the mean amount shows 14.4% of sand; while the mean, dredging up stream, is 28.4% of sand. This is explained by the fact that in dredging down stream the only power available for moving the dredge is the force of the current. The dredge cannot be forced into a bank of sand, as is possible in dredging up stream.

The mean of all observations on the *Kappa* is 16.9% of sand carried. The mean plotted line of all results shows that the proportion generally increases from the top toward the bottom; though the table shows, in one instance at least, a greater proportion near the top than near the bottom. The proportion varies from 3 to 46 per cent.

These measurements were made experimentally, and near the

close of the season, when very little time was available. They are not submitted as conclusive evidence, and it is hoped that more measurements can be made, and that, at the same time, the velocity can be ascertained and thus determine the relation between velocity and sand-bearing capacity.

An inspection of the table of results of the barge tests shows almost as wide variation in the proportion of sand carried, varying from 4 to 36 per cent.

It would seem, from all the above-mentioned data, that it is fair to assume that under normal conditions the pumps will handle from 20 to 25% of sand.

In addition to the tests of sand pumps already mentioned, certain field tests, for determining capacity only, were made by the writer during the dredging season of 1898.

The object of these tests was to determine as closely as possible the actual normal working capacity, and they were made with the regular crews, working in the ordinary way, no effort being made to obtain maximum results.

In making these field tests a location was sought where clean sand, of nearly the size of channel sand, could be found, and where there was no current, so that no material would be moved except by the dredge. The site was carefully cross-sectioned, and, after the test was completed, it was again cross-sectioned and the total amount moved was thus determined.

The *Gamma* was tested at Cow Island Bar. Eight cuts were made, aggregating 4 566 ft., and occupied 45½ hours of actual dredging. The material was chiefly a rather fine sand, with a very small quantity of blue mud. The total quantity of material moved was 45 856 cu. yd., or 1 008 yd. per hour. The average depth of cut was 7.16 ft.; the average advance was 100.3 ft. per hour; the average steam pressure was 145.6 lb.; average speed of main pump, 150 rev. per min. The vacuum on the suction pipe of the main pump was 8.6 ft. of water, and the discharge head 11 ft., or, in other words, the pump was operating against 19.6 ft. of water. The length of the discharge pipe used was 750 ft. The original test shows an average capacity of 1 523 yd. per hour.

The *Delta* was tested at Island No. 18. The material was all sand, possibly averaging a little finer than channel sand. Four

TABLE 37.—PERCENTAGE OF SAND HANDLED BY *Delta*, PETERS CROSSING, NOVEMBER, 1902.

Distance from top of pipe, in inches.	Dredging up stream. Percentage. (1)	Dredging down stream. Percentage. (2)	Dredging down stream. Percentage. (3)
4	0.143	0.047	0.125
6	.....	0.047	0.111
8	0.177	0.048	0.117
10	.....	0.058	0.080
12	0.226	0.089	0.083
14	.....	0.094	0.200
16	0.276	0.094	0.175
18	0.267	0.117	0.176
20	0.243	0.100	0.141
22	0.286	0.125	0.235
24	0.304	0.187	0.187
26	0.321	0.187	0.141
28	0.358	0.187	0.219
30	0.371	0.187	0.250
32	.....	.....	0.250
33, bottom	0.437	0.250	.....
Means	0.284	0.121	0.166
Average of Columns 1, 2 and 3			0.190

TABLE 38.—PERCENTAGE OF SAND HANDLED BY *Kappa*, PRESIDENT'S ISLAND, NOVEMBER 28TH AND 29TH, 1902.

Distance from top of pipe, in inches.	1	2	3	4	5	6	7	8	Means.
Top	0.031	0.067	.....	.....	.....	.....	.....	.....	.....
2	0.281	0.193	0.125	0.125	0.088	0.100	0.063	0.030	0.126
4	0.255	0.080	0.140	0.155	0.125	0.100	0.063	0.063	0.123
6	0.271	0.099	0.125	0.105	0.125	0.125	0.083	0.188	0.140
8	0.207	0.118	0.155	0.188	0.150	0.250	0.125	0.188	0.172
10	0.247	0.129	0.155	0.220	0.125	0.125	0.125	0.168	0.162
12	0.050	0.147	0.188	0.220	0.188	0.168	0.083	0.125	0.146
14	0.110	0.135	0.188	0.235	0.214	0.168	0.188	0.088	0.166
16	0.073	0.152	0.155	0.205	0.175	0.188	0.167	0.125	0.155
18	0.214	0.125	0.250	0.220	0.171	0.205	0.083	0.168	0.167
20	0.147	0.119	0.188	0.313	0.168	0.250	0.063	0.125	0.174
22	0.131	0.138	0.188	0.280	0.168	0.168	0.125	0.168	0.171
24	0.177	0.214	0.280	0.250	0.188	0.125	0.125	0.125	0.185
26	0.130	0.193	0.280	0.225	0.179	0.125	0.125	0.188	0.181
28	0.137	0.339	.....	0.219	0.174	0.168	0.125	0.125	0.198
30	0.171	0.467	.....	0.250	0.168	0.125	0.125	0.125	0.204
Bottom, 32	.....	.....	.....	0.250	0.250	0.188	0.250	0.250	0.238
Means	0.165	0.169	0.186	0.216	0.168	0.161	0.121	0.141	0.169

The material was ordinary channel sand, possibly slightly finer than the average, pumped through 240 ft. of 32-in. discharge pipe.

The measurements were made at the center of the second pontoon, or about 100 ft. from the stern of the dredge.

cuts were made, aggregating 2 711 ft. in length, and occupying 27 hr. 23 min. of actual dredging. The total quantity moved was 34 462 yd., or 1 259 yd. per hour. During the last cut made the dredge was pushed to its highest possible capacity without sinking the discharge pipe. Distributing to this cut that proportion of the total volume moved to which it is entitled from a consideration of the rate of advance and depth of cut, the capacity limit of this dredge is found to be 2 550 yd. per hour.

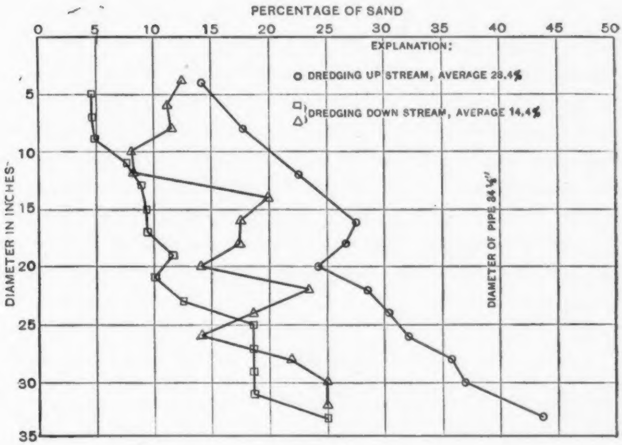
In the material encountered during the test, the capacity of the dredge, however, seemed to be limited only by the ability of the pontoons to carry the discharge pipes when loaded with the sand handled by the pumps. The average advance per hour was 99 ft.; average depth of cut 6.55 ft., average steam pressure 151.1 lb., and average speed of pump 140.9 rev. per min. The suction head was 16.3 ft., and the discharge 34.5 ft., or a total of 50.5 ft. of water against which the pump operated. The original test gives a capacity of 1 829 yd. per hour with a 67.6-ft. head. In each case, the length of the discharge pipe was 1 000 ft.

The *Epsilon* was tested, at Phillips's Bar, in medium sand, with a small amount of mud. Four cuts were made, aggregating 2 015 ft., and occupying 24 hr. 50 min.; during which time 32 407 yd. were moved at the rate of 1 305 yd. per hour. The average advance per hour was 81 ft. against a cut of 9.6 ft. The average steam pressure was 130 lb.; average speed of pumps, 178 rev.; combined suction and delivery head, 44.4 ft. of water.; 1 000 ft. of discharge pipe were used. The original capacity tests give an average of 2 553 yd. per hour, with a total head of 58.5 ft.

A test was also made with the *Zeta* at Cherokee Bar, to determine the feasibility of cutting a channel through a dry bar, and also to determine the capacity. As far as demonstrating the first-mentioned proposition, the test was an entire success. Into a dry bar a hole was cut approximately 500 ft. long, 140 ft. wide on top and having a depth of from 3.5 to 4 ft. above water and 13 ft. below water along the axis of the cut. The sides of the cut below water stood at a very considerable angle with the vertical. It would have been entirely practicable to have cut a channel entirely across the bar to deep water on the opposite side, a distance of 1 200 ft., had it been desirable to do so.

AMOUNTS OF SAND HANDLED BY *DELTA*

AT PETERS CROSSING.



MEAN PERCENTAGE OF SAND HANDLED BY *KAPPA*

NOVEMBER 28th, 29th, 1902.

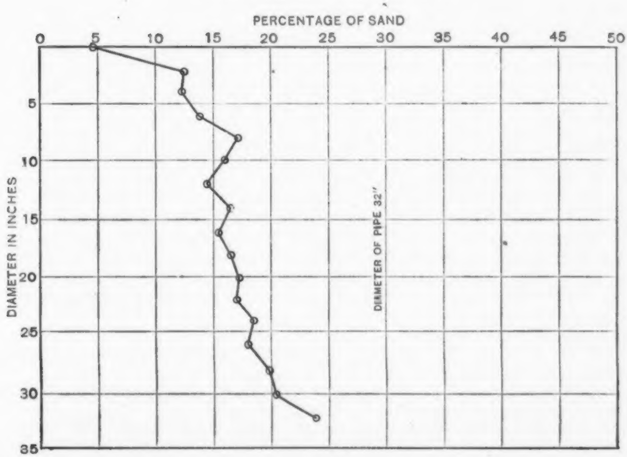


FIG. 39.

The capacity test, however, was unsatisfactory, owing to the material encountered, and cannot be regarded as showing the capacity of the dredge while at work on submerged bars of channel sand.

The bar, above water, and to a depth of 7 ft. below, was composed of pure sand, but below this, and probably extending to the depth reached by the suction pipes, it was blue mud. Had the suction pipes been raised above this mud the quantity of material moved would undoubtedly have been much larger. The total volume moved was 40 991 cu. yd., or only 652 yd. per hour. As this dredge was identical in size and construction with the *Epsilon* the difference in amount of 1 305 and 652 yd. per hour probably represents the difference in capacity when handling the two different materials, sand and mud.

Agitators.

One of the features which has received considerable attention on the dredges under discussion has been the various devices for loosening the material being dredged, to facilitate its being drawn into the suction head. They have consisted of two general types, which may be designated as the jet agitators and the mechanical agitators.

Jet Agitators.—The jet agitator, in its general form as used at present, consists of a pressure chamber, secured to the under side of the suction head at its forward or outer edge. Into the forward side of the pressure chamber are screwed nozzles, through which jets of water are directed against the material being dredged.

These jet agitators are also divided into two classes, those having nozzles of from 2 to 2.5 in. in diameter, supplied with water by a centrifugal pump driven by a direct-connected, compound engine and delivering water at a pressure of from 12 to 20 lb. per sq. in., and those having jets from 0.75 to 1 in. in diameter, supplied with water by a compound, duplex, reciprocating pumping engine under a pressure of from 40 to 70 lb. per sq. in.

The question as to relative efficiency in disintegrating and breaking down the material, with a small jet under a high pressure or a large jet under a low pressure, is still an open one. The matter of simplicity of construction, ease in operation, and absence of repairs

lies so decidedly in favor of the jets supplied by a centrifugal pump that it would overbalance any additional efficiency the jets supplied by a reciprocating pump might have, if such additional efficiency exists, and the writer does not believe it does.

The 18-in., centrifugal, jet pump on the *Gamma* was operated for five seasons without even taking off the casing for examination, and then no wear was found on either runner or casing, and only a new brass bushing for the shaft was required. The engine operating it has required very little attention, certainly no more than would be required for the steam end of a reciprocating pump.

On the other hand, owing to the fact that muddy or gritty water is being handled, the reciprocating pumps are a constant source of expense and labor in keeping them properly packed and the valves in good condition.

Mechanical Agitators.—The *Beta* was equipped with mechanical agitators originally as shown in Fig. 41.

They consisted of six barrel-shaped cutters (three for each suction head), 5 ft. in diameter and 5 ft. high, with 12 nickel-steel blades on each cutter. They were spaced 6 ft. apart, and were driven through a system of spur-gearing by a cross-compound, non-condensing engine with 14.5- and 29- in. cylinders and 18-in. stroke. The ends of the suction pipes terminated in the interior of these cutters. To support a portion of this cutting machinery, which was enormously heavy, a pontoon having a displacement of about 1 000 cu. ft. was built around the various frames and pipes. At first all the cutters worked in the same direction, and the result was that the dredge was pulled sideways out of the cut. This was remedied by changing one set of cutters to revolve in the opposite direction.

The breaks in the gearing were frequent, though the spur-gears were made of nickel-steel and the pinions of phosphor-bronze.

Owing to the excessive weight of the machinery and the almost continuous repairs necessary, it was discarded in 1898 and an entirely new suction head built, having jet agitators, supplied with reciprocating pumps.

The *Delta,* as originally built, had a mechanical agitator, as shown in Fig. 42. It consisted of twenty-two cast-steel cutters, each having four blades, mounted on a steel shaft, 6⅞ in. square, which, in turn, was supported on the upper side of the suction head, at its

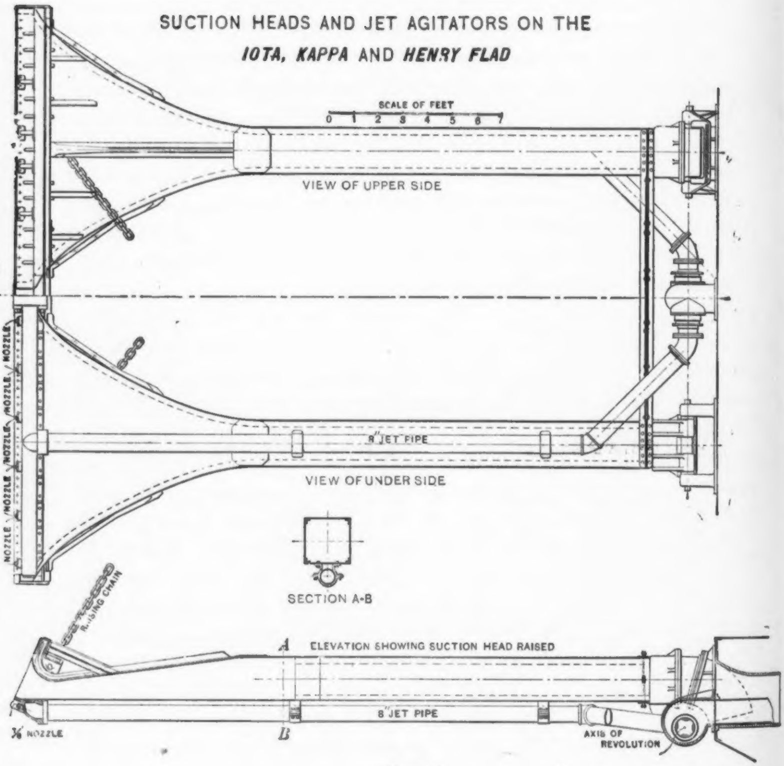

SUCTION HEADS AND JET AGITATORS ON THE
IOTA, KAPPA AND HENRY FLAD
SCALE OF FEET
0 1 2 3 4 5 6 7
VIEW OF UPPER SIDE
25'
NOZZLE
8" JET PIPE
VIEW OF UNDER SIDE
SECTION A-B
RAISING CHAIN
A
ELEVATION SHOWING SUCTION HEAD RAISED
8" JET PIPE
¾" NOZZLE
B
AXIS OF REVOLUTION

FIG. 40.

AGITATING MACHINERY, U.S. DREDGE *BETA*,

BUILT IN 1895

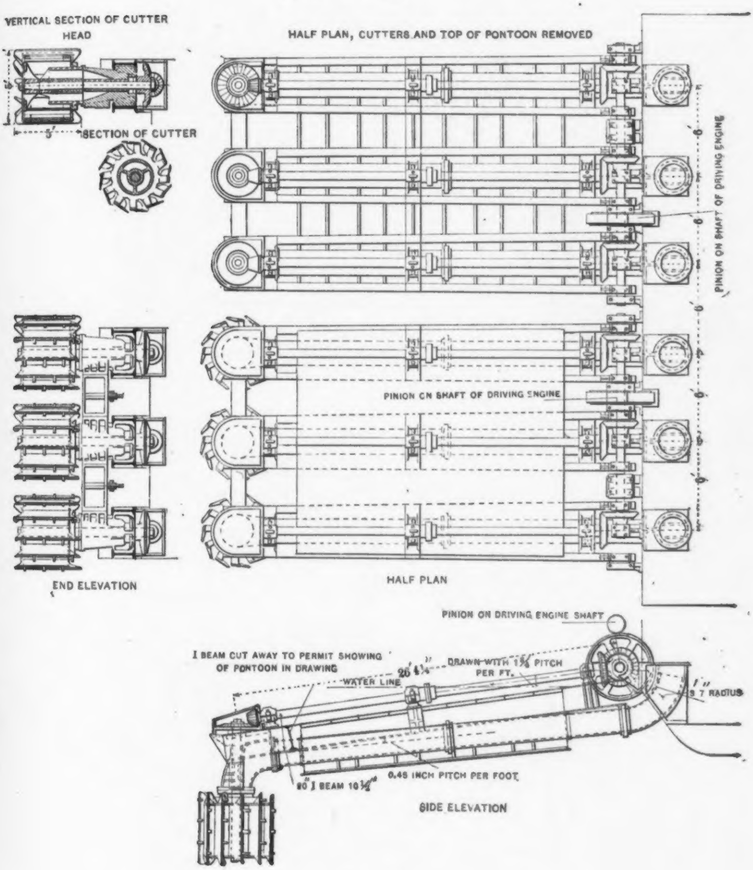
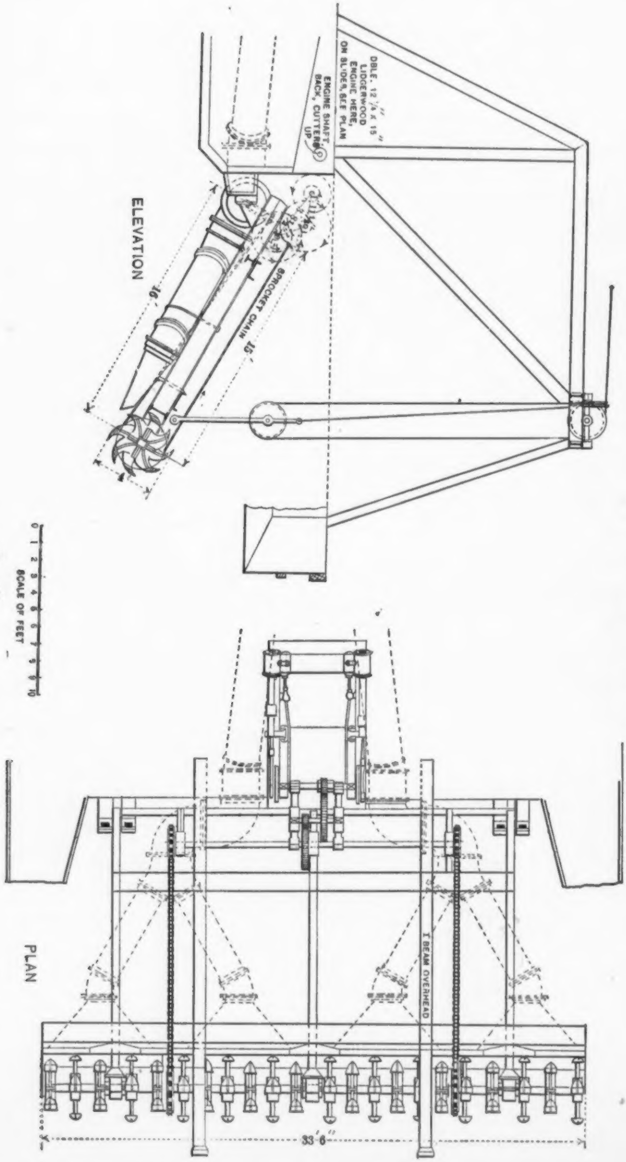


Fig. 41.



AGITATING MACHINERY U. S. DREDGE *DELTA*, AS ORIGINALLY BUILT, 1896

FIG. 42.

AGITATING MACHINERY U. S. DREDGE *ZETA*,
AS ORIGINALLY BUILT, 1897.

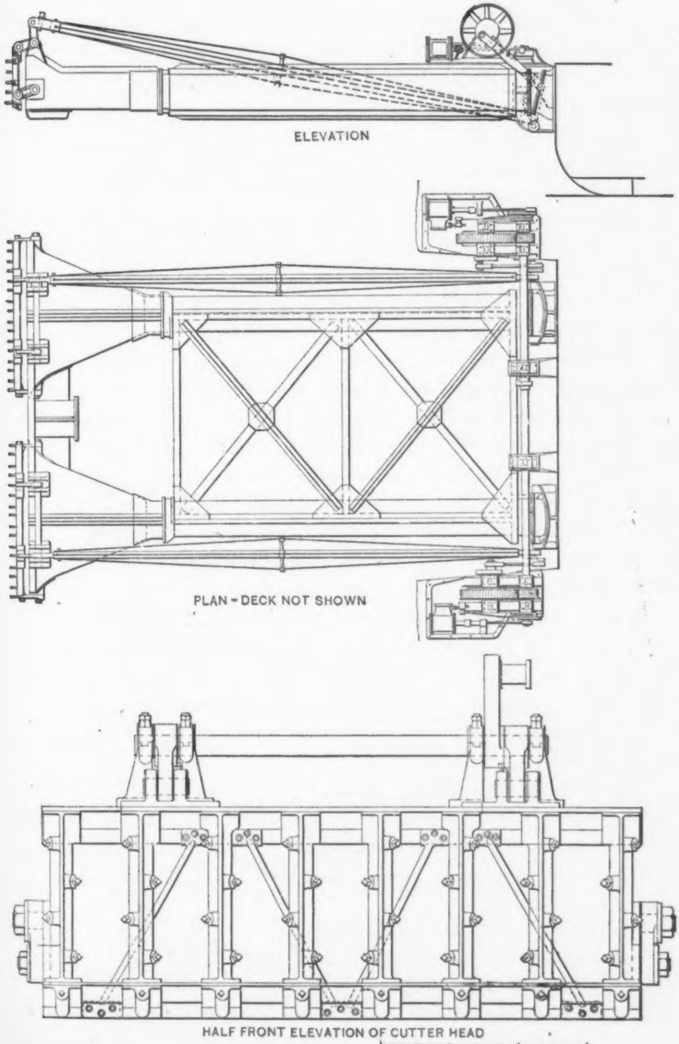


FIG. 43.

outer edge. The shaft was driven by two steel sprocket-chains connecting it by gearing to a double, horizontal engine with cylinders 12½ in. in diameter, and 15-in. stroke. This engine was attached to a sliding frame, which moved back and forth as the suction head was raised or lowered. This was necessary because the shaft driving the sprocket-chain was not on the center of revolution of the suction head.

This device worked well in clean material or material free from logs and sunken drift, but such material seldom exists over any very large area in the bars on the Mississippi. As the shaft revolved in its bearings, below water which was highly charged with mud and sand, they wore very rapidly. The teeth of the sprocket-wheel and the links of the chain also wore rapidly. The weak feature of the device was this sprocket-chain, as it was continually breaking or slipping off the wheels when the cutters became fouled in drift.

An earnest effort was made to remedy the defects of this machinery, as it was thought for a time that the fleet of dredges should have at least one equipped with mechanical cutters, for handling any material that could not be handled successfully with jet agitators. After many unsuccessful efforts to operate it successfully and economically, this machinery was finally abandoned, in 1901, and a new suction head installed, having a jet agitator.

The *Zeta* was also equipped with a mechanical agitator, of the form shown in Fig. 43. This device consisted of open frames, provided with teeth much like a harrow. It was attached to the suction head in front of the suction opening by links, which permitted motion parallel to the plane of the opening. This motion was obtained by bell-cranks, connecting with a long pitman extending to the rear of the suction well, where it connected through rocker-arms to a second oscillating crank operated by an engine.

The tests of this dredge seemed to indicate that the capacity of the pump was decreased very materially by the use of this agitator, and, as it was impossible to operate it for more than 2 or 3 hours without breakage, it was discarded very promptly and a jet agitator substituted.

At present, all the dredges are equipped with jet agitators, which are very simple in construction, give no trouble by breakage, and are effective and satisfactory in operation.

Provision for Dredging Up and Down Stream.—It will be noted, from the foregoing descriptions and illustrations of the agitators, that provision is made for dredging in one direction only. This condition causes considerable delay, due to the loss of time necessary in allowing the dredge to drop back to the end of the hauling cables after the completion of each cut.

To avoid this delay in changing cuts, the suction head on the *Delta,* when it was changed from a mechanical to a jet agitator, was supplied with a device enabling the dredge to be operated in either direction.

The characteristic features of this device are shown in Fig. 44.

SUCTION HEAD ON U. S. DREDGE ***DELTA,***
FOR DREDGING UP AND DOWN STREAM

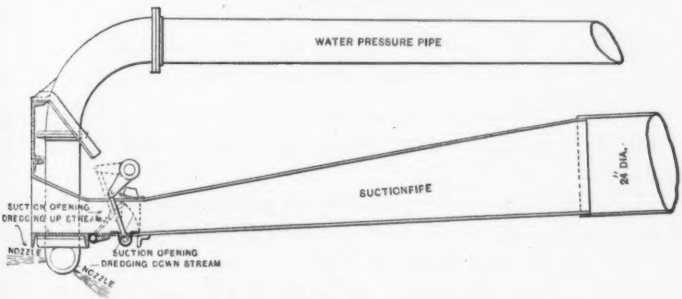


Fig. 44.

The head, as a whole, has the same general form as that used on the other dredges. The pipe supplying water to the pressure chamber is above the suction head. Just back of the pressure chamber there is an opening in the bottom plate of the head, having a width a little greater than the depth of the head at this point, and extending the whole length of the head. In dredging up stream this opening is covered by a shutter, hinged on one edge. When it is desired to dredge in the opposite direction, this shutter is lifted by links and cranks connected to a hydraulic cylinder. The shutter then closes the forward opening into the head and permits the entrance of material into the bottom. As the suction head, when

dredging, is inclined at an angle of 40 or 45°, it permits dredging against a face below and down stream from it.

The pressure chamber is circular, and is provided with nozzles in the usual manner. It is connected with the pressure pipe through a swivel tee, and is free to revolve in supporting bearings. It is connected with and revolved by the same mechanism that operates the shutter, and in such a manner that when the forward opening into the suction is open the jets are directed up stream and when the position of the shutter is reversed the jets are directed down stream.

This device works very satisfactorily, and has resulted in a very material saving of time when dredging in a fairly loose material. As there are no means provided for driving the dredge down stream, other than the force of the current, the head, of course, cannot be forced into the face of the material when dredging down stream, as it can be in the opposite direction.

Floating Discharge Pipe.

Another feature connected with the dredges under consideration has been the method of supporting the discharge pipe beyond the dredge.

Fig. 45 shows cross-sections of the pontoons used for this purpose on the *Alpha* to *Zeta,* and also more complete drawings of those used with the *Iota, Kappa* and *Flad.*

On the first six dredges the discharge pipe passes through the stern of the dredge, at about the water line, being submerged from one-half to two-thirds of its diameter. The floating discharge pipe is supported at about the same elevation, the amount of submergence depending somewhat on the amount of sand being carried. These discharge pipes have already been fully described.

In the design of the *Alpha* it seems to have been considered that 10% of sand would be as large a proportion as would ever be carried, and the buoyancy chamber of the pontoon was proportioned with this idea in mind. It was very soon learned that this proportion could be very easily exceeded, 25% not being uncommon, while a considerably greater percentage has been reached, as has been mentioned.

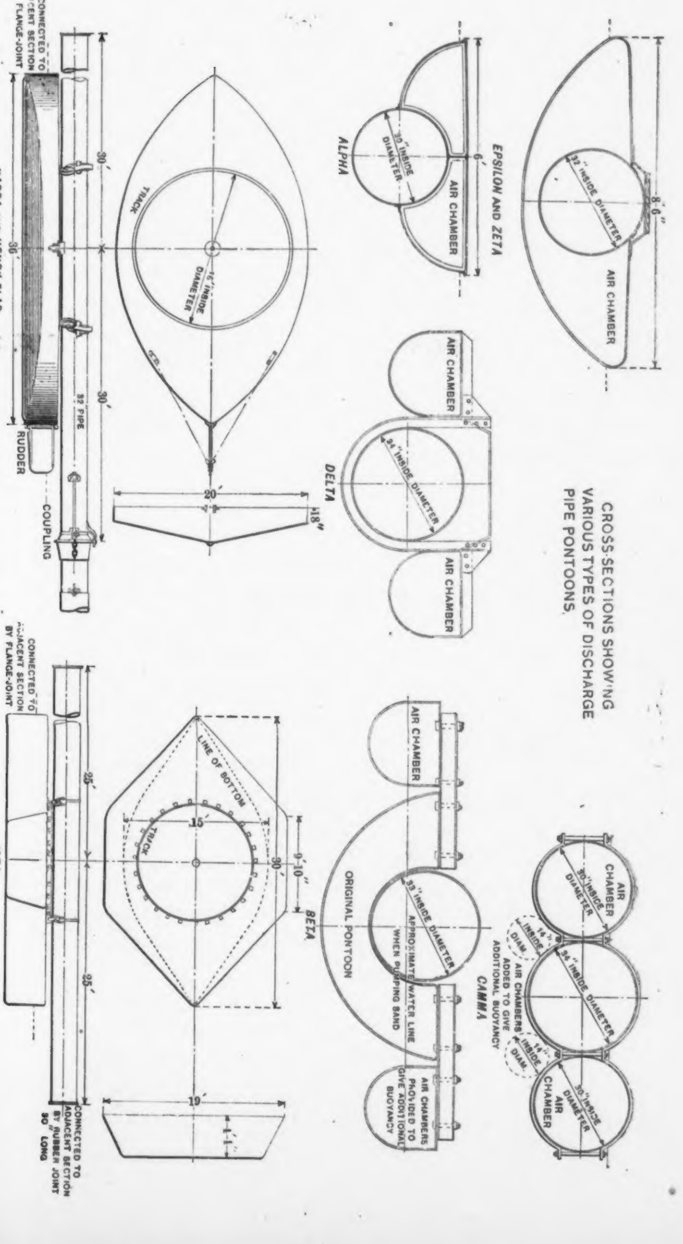

CROSS-SECTIONS SHOWING VARIOUS TYPES OF DISCHARGE PIPE PONTOONS
EPSILON AND ZETA
ALPHA
AIR CHAMBER
30" INSIDE DIAMETER
6'
32" INSIDE DIAMETER
8'-6"
AIR CHAMBER
DELTA
AIR CHAMBER
34" INSIDE DIAMETER
AIR CHAMBER
GAMMA
AIR CHAMBER
30" INSIDE DIAMETER
14" INSIDE DIAM.
AIR CHAMBERS ADDED TO GIVE ADDITIONAL BUOYANCY
34" INSIDE DIAMETER
14" INSIDE DIAM.
AIR CHAMBER
30" INSIDE DIAMETER
AIR CHAMBER
33" INSIDE DIAMETER
APPROXIMATE WATER LINE WHEN PUMPING SAND
ORIGINAL PONTOON
AIR CHAMBERS PROVIDED TO GIVE ADDITIONAL BUOYANCY
TRACK
16' INSIDE DIAMETER
20'
18"
BETA
LINE OF BOTTOM
TRACK
15'
30'
9'-10"
19'
4'-1"
KAPPA AND HENRY FLAD
CONNECTED TO ADJACENT SECTION BY FLANGE-JOINT
30'
36'
30'
32" PIPE
RUDDER
COUPLING
IOTA
CONNECTED TO ADJACENT SECTION BY FLANGE-JOINT
25'
25'
CONNECTED TO ADJACENT SECTION BY RUBBER JOINT 30" LONG

FIG. 45.

In consequence of this assumption of the low proportional amount of sand which could be pumped, the pontoons of the discharge pipes of the *Beta, Gamma* and *Delta* proved to be deficient in buoyancy. This deficiency, on the *Beta* and *Gamma,* was remedied as shown; for the *Delta,* new circular pipes, 32 in. in diameter, arranged as for the *Gamma,* were supplied.

The pontoons with the *Epsilon* and *Zeta* have ample capacity. Owing to the fact that these pontoons are partially submerged for the full length of the pipe, they present a large surface to the action of the current in the river, and it is found impracticable to deflect them to any very great amount to either side of the thread of direction of the current. As the axis of the dredged cut should coincide with the direction of the current, enough pipe must be supplied to reach from the dredge to deep water below the bar, or, owing to the limited deflection possible, the dredged material will be deposited too near the edge of the cut.

Another disadvantage is the extremely difficult and unpleasant feature of connecting the various sections of partly submerged pipe by short rubber joints, which are slipped over the ends of the iron pipe and secured by clamping bands.

For reasons already stated, it is desirable to make the discharge pipes as short as possible, and for this reason provisions were made on the last three dredges for deflecting the discharge to the side of the dredged cut at a considerable angle; in fact, it is possible, and desirable in some cases, to lead the discharge pipe off at right angles to the dredge.

For this purpose the discharge pipes on these dredges are elevated about 2 ft. above the water and are carried on pontoons, as shown on the drawing. Connections between adjoining sections are made alternately with rigid flange joints and, on the *Iota,* with rubber joints, and on the *Kappa* and *Flad,* with a universal ball and socket joint. The pontoons are free to revolve under the pipes and their axes can be set to coincide with the current. These pontoons have proved very satisfactory in operation.

OPERATION.

The project under which all the dredges are operated contemplates the maintenance, by dredging, of a navigable channel having

a depth of 9 ft. and a width of 250 ft. at all times of the year, except when closed by ice, and at all stages; the amount of dredging required in any one season, evidently, then, depends, to a very large extent, on the stage of the river.

The river has a range in stage of somewhat more than 51 ft. at Cairo and a little more than 42.5 ft. at Memphis, but dredging, of course, is confined to the lower limits of the stages.

That the amount of dredging required will depend on the stage, is true only in a general sense, for, within reasonable limits, say 3 or 4 ft. on the Memphis gauge, the depth of water in the channel, without dredging, depends as much on the amount and rapidity of fluctuations in stages as on the actual elevations of the stage of water at any one time. In other words, there may be, and usually is, a greater depth of water in the channel during a season of slowly falling or stationary stage, even though this stage reaches a minimum on the gauges, than during a season of short, sharp fluctuations in stage, the minimum of which may be several feet higher on the gauges.

This point was particularly well illustrated during the season of 1901. After a slight rise, bringing the gauge at Memphis to about 8 ft., about October 1st, the river began to fall, and by October 10th had fallen to about 2.5 ft. on the gauge. From this time the river fell very gradually until about December 3d, when it reached a stage of about 0.5 ft. below zero and remained near zero for another week; a period of about 60 days, during which the river was at extremely low stage. In spite of this fact, no dredging was required after about November 24th, as there was at that time a depth of not less than 10 ft. in the channel.

For the reasons mentioned, and the fact that the stage cannot be forecasted, the amount of dredging required in any one season cannot be foretold, and the dredges assume the character of an insurance feature; they are put into the field at the beginning of the ordinary low-water season, in readiness to do such work and in such locality as is required and as the channel conditions develop.

Generally speaking, the low-water season, during which dredging may be required, extends from about August 15th to December 15th, and the dredges, or some of them, are usually held in commission during that time, though it may happen that for a considerable portion of this time their services may not be required.

In making comparisons of the amount of work done by these dredges and others, this feature of the conditions to be met should be borne in mind. Instead of a predetermined amount of dredging required, for which a dredge or dredges may be prepared, put in commission and retired on completion of the work contemplated, it is necessary to be prepared to meet conditions which can be forecasted only a few days before they become facts, and the time allowed for doing the work made necessary by these conditions is equally brief.

During September, October and November, 1903, the stage remained considerably above the ordinary mean stage for these months, and very little dredging was required. Near the end of November there was every indication that this stage would be maintained or not lowered to any great extent. Contrary to these predictions, the river at Cairo, between December 2d and 20th, fell 9.1 ft., an average fall of slightly more than 6 in. per day. This very rapid and unexpected fall produced unexpected conditions, and made necessary a large amount of dredging, which, in order to maintain the requisite channel depths, should be done very quickly and at a number of places at the same time. Unfortunately, owing to these unexpected conditions and other difficulties of operation, the writer is forced to admit that for a few days during this period the full channel depth contemplated was not maintained. This, however, was not due to the inability of the dredges to do the work required, but to an error in judgment in retiring some of them from the field too soon, and also owing to a shortage of coal.

A brief description of general methods of operation may be of interest.

The Superintendent of Dredging Operations is provided with a suitable steamboat, on which his headquarters are maintained. As the low-water season approaches, he examines the river, making soundings of all crossings, and from this time until the dredging season is over he is constantly inspecting the river, night and day, keeping himself fully informed as to the location and condition of the channel at all points, and directing the operations of survey parties and dredges.

The part of the river which may require dredging, and about which he must be fully informed as to its condition, extends for

500 miles below Cairo. The greater part of the dredging work, however, is usually confined to about 250 miles of river.

Three survey parties, also quartered on small steamboats designed especially for this purpose, are sent into the field to make surveys of such bars as are likely to become troublesome. These surveys are hydrographic, entirely, and consist in thoroughly developing the shape and elevation of the bottom by means of soundings, properly distributed and located. These soundings are reduced to mean low water, and the resulting maps show depths at a uniform stage of the river; the shape of the bottom is indicated by contours and thus any changes in the river bed are indicated very clearly on the maps of the same locality made from surveys on different dates.

These surveys are repeated from time to time, and the changes indicated are studied carefully. Should dredging be necessary, these maps and surveys are made before and after the dredging is done, and they serve to show clearly the results obtained.

The writer wishes to emphasize the importance of these surveys and the necessity of accuracy in the construction of the maps. The efficiency of the dredges in creating and maintaining suitable channels over the troublesome bars depends almost wholly on the correct location of the channel to be dredged. No fixed rules can be laid down governing this location, and the determination in each instance must arise from a careful study of conditions, which conditions can only be known through the results of careful, accurate surveys, supplemented, of course, by a knowledge of surface conditions, direction of current, etc.

The proposed channel must lie so as to coincide with the effort of the river and take advantage of its direction and force for enlarging the artificial route.

The location of the proposed dredging is laid down on the maps, and the dredge masters govern themselves accordingly. These maps accumulate very rapidly, and there are now several hundred. A study of these maps is quite interesting, but is beyond the limits of this discussion.

As an example, one series of a single locality,* that of Bixby's Towhead in 1902, may be mentioned.

The survey of August 22d to 24th shows that the deepest water

* Report of the Chief of Engineers for 1903, Plates 7, 8, 9, 10, etc., of Appendix 1 D.

from the left-hand pool to the pool along the right bank was near the foot of Williams' Towhead, and this was the channel as steamboats ran it at that time. It must be remembered that at the time the survey was made the stage was 10.1 ft. above mean low water and that actual depths at that time, therefore, were that much more than those shown on the map.

Owing to the strong current down the left bank and crossing over to Bixby's Towhead, and to the general rule, which is the result of experience, that it is desirable to locate the dredged cut as far down stream as possible, it was decided to dredge as indicated, though the amount of work to be done was apparently considerably greater than would have been required near the foot of Williams' Towhead.

This upper channel filled up as the river fell, became impassable, and does not appear on the later maps.

The survey of September 9th, three days after dredging, does not show very great results, as the stage was still 11 ft. above low water, and the dredge can only dig to a depth of about 18 or 19 ft. The 5-ft. contour, however, goes across the bar where dredged.

Owing to a rising and high stage, dredging at this point was suspended from September 6th to 14th; it was resumed on the latter date and continued, with some interruptions, until the 24th.

Surveys made on September 28th show in a very marked manner the results of this dredging. Owing to a rise of several feet in the river, dredging was not resumed until October 28th. The survey taken the day before indicates that a considerable amount of filling had taken place in the dredged cut, though its existence is still well defined. This filling is a characteristic feature connected with a rising river.

The survey of November 9th, after the completion of dredging, shows very clearly the results obtained. The channel was straight and easily navigated, and remained in good condition for the remainder of the year.

It is desirable to begin on a bar which will require dredging as soon as the stage of the river and depth of water are such as to permit making a cut of moderate depth with the length of suction head available.

By this means a single dredge is able to create a channel through

a bar and move to another one before the depth of water becomes troublesome; the assistance received from the current in scouring out the artificial channel will also be greater at a higher stage.

It is always the practice to dig as deep as the length of the suction head will permit. The writer believes this to be the correct method to use, as the quantity of water, and consequently the velocity of the current flowing through the cut, will certainly be increased with the size and depth of the cut.

From what has been said it will be noted that the cuts are made in a longitudinal direction in reference to the channel, and the dredged channel is made of the requisite width by making the necessary number of parallel cuts.

On the Mississippi, where the action of the current is depended on very largely to aid in the formation of a channel, this method of dredging is much more efficient than the lateral system, or dredging to the full channel width by swinging the dredge as it advances.

The channels to be dredged are now located invariably with their axes coincident with the direction of the current, though this direction will probably not give the shortest distance across the obstructing bar. Experience has shown that it is practically impossible to maintain a dredged channel the axis of which lies at any very considerable angle with the current.

Since 1898, when a fleet of dredges adequate in number to do the required amount of work was made available, the channel depth of 9 ft., as contemplated by the project, has been maintained, except possibly for a few days at a time when the fall in the stage of the river has been so rapid that unexpected conditions were created and very little time was available for meeting them. At no time in the writer's knowledge has a dredge failed to open quickly a channel of ample depth and width through any obstructing bar which has been attacked.

Prior to the adoption of the dredging project, low-water channel depths of 4 and 5 ft., extending over a period of several weeks, were not uncommon.

In view of the success in securing, thus far, such a satisfactory improvement of the low-water channel, and that both the present standard depth and width can be increased to advantage, and that

other applications of dredging to advantage are possible, the Commission is now building another dredge, the tenth in the series.

This dredge will be of the self-propelling type, and of the following general dimensions:

Length between perpendiculars	210	ft.
Beam moulded	44	"
Total width over guards	78.5	"
Depth moulded	8.5	"
Depth at center line	9.25	"

The hull will be of steel, throughout, built similar to the *Kappa* and *Flad,* but of stiffer construction. The main sand pump will be similar in form to those of the *Kappa* and *Flad,* and will have a runner 90 in. in diameter, with 6 blades, and with a 36-in. discharge pipe. It will be driven by direct-connected, tandem, compound engines, supplied with a surface condenser.

The agitators will be of the water-jet type, served by a 20-in. centrifugal pump.

The suction head will be fitted to dredge both up and down stream. The propelling engines will be compound, of comparatively short stroke, and geared to the wheel shafts.

In detail, this dredge will represent the results of ten years' experience.

TRANSACTIONS

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

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DISCUSSION ON

DREDGES: THEIR CONSTRUCTION AND PERFORMANCE.

By A. W. Robinson, J. L. Le Conte, George Higgins, William Mayo Venable, C. W. Sturtevant, Lewis M. Haupt, William M. Hall, W. B. Gregory, F. B. Maltby and J. C. Sanford.

A. W. Robinson, M. Am. Soc. C. E., Montreal, Canada. (By letter.)—Major Sanford's paper is an interesting and valuable record of the fleet of hopper sand-pump dredges belonging to the United States Government. Owing to the fact that so many of them—eleven in all—were only built or are building in 1904, the statements of performance given in the paper are very meagre, and it is to be hoped that Major Sanford will collect and publish full data of the results obtained with these later dredges as soon as they are available. Mr. Robinson.

These dredges all work while under way, with their propelling engines in motion, scraping up a very small section of cut at a time. In this they differ from most European dredges of this type, which are fitted with larger pumps as a rule, and pump large quantities of sand from a limited area and with no expenditure of power for propelling. The United States dredges, however, make a better bottom, and, in working across-bar, the value of the deepening is available from the beginning, or nearly so.

The small size of the pumps on these dredges is noticeable. The writer thinks that size of pump should be limited by the ability to

Mr. Robinson. propel the vessel with the suction pipe on the bottom, and by the ability of the hoppers to precipitate a fair percentage of the sand without washing overboard by the use of too large a stream. The pumps on these dredges could be made considerably larger without going beyond the above limits, and thus increase the capacity of the dredge. The early dredges were equipped with 15-in. pumps, and this size was followed for some time and then gradually increased to 18-in. and 20-in., which appear to be the largest yet used. The 20-in. pipe on the side of the *Chinook*, for example, looks almost absurdly small. The writer sees no difficulty in making these flexibly connected suction pipes of larger size, and has himself used them up to 34 in. diameter over the side of a moving vessel. The form of drag should be made to offer as light resistance to propelling as possible, and in this respect the present plow or scraper form might be much improved.

It is remarkable that the best record quoted of cost per cubic yard of work done (2¼ cents) was made by the *Sabine*, a little dredge with only 10-in. pumps. This shows that mere size alone does not produce economy, but that with favorable conditions and low operating cost small units rapidly worked can show excellent results.

It is noticeable that all the engines both for pumping and propelling are compound, except in one small dredge which has simple engines for pumping, and the *Chinook*—a converted steamship—which has expansion engines for propelling. No reason is given for this in Major Sanford's paper, and it is difficult to assign any, unless it be economy in first cost. The slight extra cost of triple-expansion engines would be much more than met in the better economy and greater ease of running. In former days there were some who, being accustomed to the good old compound engine, feared that the triple meant some new and untried complication, and that it would be more difficult to keep in order. The reverse is really the case, and it is hardly necessary now to state that the faster revolutions and subdivided strains with lighter pressures on all the bearing surfaces of the modern triple engine make it more durable and hence easier to manage and maintain than its predecessor, the compound, notwithstanding the fact that it has three sets of parts instead of two. High speed of revolution is specially desirable for a centrifugal pump, if its diameter is to be kept within the limits of good working efficiency, and this is more readily obtained with a triple than a double engine while the economy is much increased.

Mr. Maltby's paper is exceedingly useful in supplementing the previously published information on this subject and bringing it up to date. Much of the matter contained in the paper is not new, but

it aids in the comprehension of the general subject to have it presented again. **Mr. Robinson.**

The writer cannot speak too highly of the value and importance of the data which have been made available by the publication of the tests of the performance of hydraulic dredges on the Mississippi made by the Government. Mr. Maltby states that he has recomputed much of the data of the earlier tests, and he now publishes them in what he claims to be a corrected form. The writer, however, desires to call attention to one or two statements with which he cannot agree. On page ~~469~~ 487 the author states that an error was made in the original calculations of pump performance, in taking the head in feet of water, instead of in feet of material being pumped, as should have been done. As the term "head" is here used as an expression of observed pressure, and not as the actual height, the writer is unable to see that it makes any difference in the work done, whether we compute this work from the lower head due to heavier material or the slightly higher heads due to water. The writer would suggest when dealing with fluids of varying density, that the pressure be expressed in pounds per square inch.

On page ~~469~~ 487 the author states that the "head of material pumped is to the total head of water observed as the weight per cubic foot of material pumped is to the weight of water." This ratio should be inversely and not directly as stated.

In Table 33 Mr. Maltby states that the mercury in the gauges connected with suction and discharge pipes fluctuated very rapidly and irregularly through a space of, sometimes, two or three inches. The readings from these gauges, therefore, were subject to the estimation of the observer, and an inch or two of mercury would make a great difference in the results which are set down in the table to two places of decimals.

In the recomputed results which the author gives in Table 30, there are several statements of pump efficiency which the writer must be excused for refusing to believe; for example, in Column 24 the Dredge *Epsilon* is credited with efficiencies of 81.4 to 96.2. It is to be regretted that as this pump apparently did so well it could not have covered that other 3.8%, and thus held the proud record of being a perfect pump of 100% efficiency. Possibly if the gauges had fluctuated a little more it might have done so or even exceeded it. In the first two tests of this dredge, the efficiency varies from 68.52 to 82.66. Here is a variation of 14% in efficiency while the tables show a variation of nearly 50% in velocity, and the revolutions, indicated horse power, and cubic yards of sand per hour, remain practically constant. It is, of course, possible that considerable variation in the flow might be produced by a partial choking either of suction or discharge pipes, but observations such as these,

Mr. Robinson. taken under rapidly varying conditions, are very misleading. There is nothing about the design or construction of the pump of this dredge which differentiates it very materially from several of the other dredges, and, in fact, it is a duplicate of the *Zeta,* which yielded very different results. The writer is very distrustful of the performance registered by these short-time barge tests, and, although many of the observations could be taken with reasonable accuracy, there are elements of uncertainty and widely varying conditions which it is apparently impossible to observe accurately and allow for.

In Table 34, there are two identical dredges, the *Kappa* and *Henry Flad,* which give widely varying efficiencies at extremes of speed. In the case of the *Kappa* the highest efficiency is obtained at the slowest speed, and, in the case of the *Flad,* the relation is reversed, and the highest efficiency is obtained at the highest speed. There is no apparent reason why this should be so, and in default of satisfactory explanation we are left to conclude that it is due to errors of observation.

In Table 33, Mr. Maltby gives data and results of tests of main pumps, 1902. These presumably were not barge tests, although the fact is not clear from the paper, nor is the duration of these tests stated. It would appear that this table records results when pumping water only, although the table does not so state.

The writer agrees with Mr. Maltby that the runner of a dredging pump should be of the enclosed type, as stated on page 452, and all modern dredging pumps are now made with enclosed runners.

As has been brought out in the paper, the use of mechanical agitators has been discontinued on the Mississippi, and the only aid to the dislodgment of the sand at the suction pipe is that obtained from the use of water jets. This does not mean that the use of mechanical agitators is to be avoided, but only that the use of the particular agitators employed in the early experiments on the Mississippi were unsuitable and unnecessary for the conditions as they there exist. The sand of the Mississippi in which these machines have to work is all of recent deposit and is readily picked up by the pumps without mechanical excavation. For other classes of material, however, and in other conditions, the writer believes mechanical excavation may be advantageous and essential, and he has used different forms of cutting apparatus in his own practice which have been reliable in service and given good results.

Mr. Le Conte. L. J. Le Conte, M. Am. Soc. C. E., Oakland, Cal. (By letter.)—The writer has been very much impressed by Mr. Hersent's remarks about proportioning the capacity of the dredge to the work to be performed. It goes without saying that a mammoth dredge with a capacity of 2 000 cu. yd. per hour will make a good record in soft digging, where the material being excavated will naturally flow to

the suction. On the contrary, even in ordinary stiff digging, the capacity of a dredge is measured by the capacity of the cutting apparatus to feed the pump, which is usually very limited. Hence it follows that a mammoth dredge is, as a rule, unfit to do stiff or hard digging, and it would be far better and would save money to lay up such a dredge and do the hard digging with a medium-sized dredge. It becomes, therefore, a matter requiring a great deal of judgment to decide just what type of dredge is best, and what capacity of dredge is best adapted to any particular piece of harbor work. At all events, the first thing to do in any given case is to classify the character of the material to be dredged. Delegate the soft digging to the mammoth dredge, with capacity of 5 000 h. p.; the sandy mud to the 1 000-h.p. dredge; the muddy sand to the 600-h.p. dredge; and, finally, the hard-pan and tough clay to the 400-h.p. dredge. This distribution of the work is nothing more than a wise attempt to gauge the capacity of the dredge to the ability of the cutting apparatus to feed the pump with dredged material. Should the present designs for the cutting apparatus be materially improved upon, and such improvements are being made every day, the horsepower capacity of the dredge most suitable would be correspondingly increased in proportion to improvement made in the capacity of the cutting apparatus. Mr Le Conte.

George Higgins, M. Inst. C. E., Melbourne, Victoria. (By letter.)—The writer wishes to congratulate Mr. Maltby upon the very valuable nature of the information which the experiments afford. He trusts that many minds will set to work with the figures given, and derive from them much that will throw light upon the many points in the science of centrifugal pumps which need clearing up. Mr. Higgins.

One important part of the ordinary theory of these pumps, to which the writer's attention was directed by Mr. W. M. White of Philadelphia, is, he thinks, open to question. This refers to the expression, $\frac{w\,V}{g}$, for the energy imparted to each pound of water per second by virtue of the motion of the runner, w, denoting the tangential velocity of the water at the periphery of the runner, V, the peripheral speed of the runner, and g, the acceleration due to gravity, the units being feet and seconds. Now, in deducing the expression, $\frac{w\,V}{g}$, the usual procedure is to ascertain the change of angular momentum of water per second and use this as a measure of the angular impulse. So far so good. But the next step seems to be wrong. The angular impulse is multiplied by the angular velocity of the runner, and the product called the work done per second. Now, in most runners the angular velocity of the water is less than the angular velocity of the runner, and, if we follow

Mr. Higgins. any one particle of water as it glides along the surface of a backward-curved vane, we must admit that the points of the vane, which, successively, impart impulses to the particle of water, are not upon the same radius. But it is the angular velocity of any one radius that measures the angular velocity of the runner, therefore, the angular velocity with which the point of application of the force between vane and particle moves is less than the angular velocity of the runner. For instance, in Fig. 46, let $O\ A$ be the radius passing through the particle when it is at a distance, $O\ B$, from the center, and suppose that while $O\ A$ moves to $O\ A'$, the particle travels outward along the vane to C. Then it is evident that, when the vane is curved backward, the angle, $A\ O\ C$, will be less than $A\ O\ A'$; in other words, the angular velocity of the point of application of the force between vane and particle will be that of the particle of water and not that of the runner. Hence, we must write:

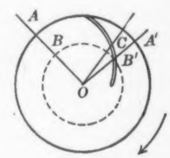


FIG. 46.

$$\begin{aligned}&\text{Angular impulse} \times \text{angular velocity}\\&= \frac{W}{g} w\,R \times \frac{w}{R}\\&= \frac{Ww^2}{g}\end{aligned}$$

= Energy (corresponding to angular motion) imparted to the W lb. of water which leave the runner per second = work done in imparting angular motion to water per second.

But even this statement needs to be qualified. First, we must take into consideration the outward, or radial, motion of the water. Denoting the radial resolved part of the velocity at the periphery by u, we must add $\frac{Wu^2}{g}$ to the expression, $\frac{Ww^2}{g}$, and the sum will represent the total energy, subject, however, to a further qualification, *viz.*, secondly, the vanes may not be so shaped that the angular velocity of the water shall be uniform or that it shall be continuously accelerated. Thus, in the case of the *Gamma's* pump, the curvature of the vanes is so great, and the angle between a tangent to the vane at the tip and the tangent to the periphery of the runner is so small, that the value of $w^2 + u^2$ is longer about 3 in. in from the circumference than at the circumference. This means that the energy due to motion, which is represented partly by centrifugal pressure and partly by velocity head, cannot be measured at the periphery, but at a radius where its value is a maximum. The water will generally gain in pressure as it slows down outside the position of

maximum energy of motion, and, if the spaces between the vanes run full, or nearly so, the water will do work on the runner. Mr. Higgins.

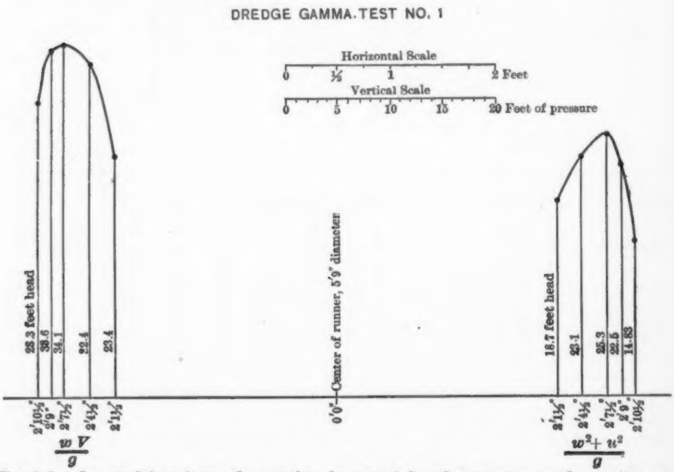
TABLE 39.—CENTRIFUGAL PUMP TESTS BY F. B. MALTBY, M. AM. SOC. C. E., MISSISSIPPI RIVER COMMISSION, 1902; DEDUCTIONS BY GEORGE HIGGINS, MELBOURNE, 1904.

Name of dredge.	Test number.	Periphery speed of runner, in feet per second. V	Tangential velocity of water as it leaves runner, in feet per second. w	Radial velocity of water as it leaves runner, in feet per second. u	Head, in feet, $\frac{w^2+u^2}{g}$. H	Head actually measured, in feet.	Discharge per second, in pounds. W	Horse power corresponding to motion imparted to water. $W \times H$	Indicated horse power of engine.	Horse power if H be taken as $\frac{w\,V}{g}$.	Remarks.
Delta	1	44.73	41.11	2.40	52.67	33.79	6 765	648	737	709	
	3	45.47	41.77	2.45	54.37	34.55	6 905	681	784	741	
Epsilon	2	49.66	40.45	8.53	53.07	37.35	7 400	714	681	840	Some inaccuracy here.
	5	51.47	41.96	8.81	57.09	40.13	7 640	793	766	931	do.
	7	54.48	44.79	8.97	64.80	42.90	7 780	917	867	1 075	do.
Zeta	3	51.17	44.60	6.09	62.90	48.32	5 700	651	690	735	
	5	52.67	46.05	6.13	67.03	49.46	5 750	700	734	787	
Iota	3	54.00	44.55	6.18	62.83	43.25	6 620	756	818	899	
Kappa	5	46.57	41.65	2.93	54.14	42.52	7 420	730	818	813	
Henry Flad	4	46.20	42.25	2.35	55.60	42.20	5 930	600	635	654	
*Gamma**	1	39.05	28.09	5.10	25.50	19.95	5 420	251	297	337	

* In this case, the figures refer, not to the periphery of the runner, but to a circle within the runner concentric with it, where the head arising from the motion of the water is a maximum. Outside this circle, velocity head is converted into pressure, and some work is done on the runner. The reason is found in the recurvature of the vanes.

A comparison of the three last columns of figures on the accompanying Table 39 will show that the experiments under discussion seem to support the view held by the writer. In all the experiments dealt with in this table, except the three referring to the *Epsilon*, the calculated horse power, if H be taken as $\frac{w^2 + u^2}{g}$, bears a reasonable proportion to the indicated, the difference representing frictional losses in engine and bearings and the frictional resistance to the motion of the runner; not, of course, including any fluid friction caused by flow. The last column of figures shows what the horse power would be if it were correct to calculate it on the supposition that $H = \frac{w\,V}{g}$. In nearly every case it is greater than the indicated horse power. The writer is not able, at present, to account for the discrepancy in the case of the *Epsilon*, where the horse power

Mr. Higgins. corresponding to the motion imparted to the water, as calculated on the supposition that each pound has $\dfrac{w^2 + u^2}{g}$ units of energy imparted to it per second, appears to be greater than the indicated horse power. It is true that its casing is better formed than those of most of the other dredges—the whirling not being interrupted by any projecting lip, and space being provided for whirling to take place; also, its runner is of better form than those of most of the other dredges; but all this would not give us a perpetual motion result.



Total heads resulting from the motion imparted by the runner to the water at various distances from the center. The maximum head is found about 3 in. inside the periphery of the runner; outside this place, the water does work on the runner, losing velocity head in doing so. There is, however, a gain in pressure, as recorded by the gauges used in the experiments.

FIG. 47.

Possibly some clue may be gained by examining the energy imparted to each particle of water as it moves outward. Time does not allow of this being done; but an investigation of this kind made in the case of the *Gamma's* pump (see Fig. 47), shows how the energy of motion is not always a maximum at the periphery of the runner. Curves are drawn to show the position of maximum energy of motion on both the suppositions in dispute.

Table 40 is prepared to show how loss of head arises in each of the pumps experimented with by reason of the casings and outlets not being suitably designed for the conditions.

Mr. Higgins.

TABLE 40.—CENTRIFUGAL PUMP TESTS BY F. B. MALTBY, M. AM. SOC. C. E., MISSISSIPPI RIVER COMMISSION, 1902; DEDUCTIONS BY GEORGE HIGGINS, MELBOURNE, 1904.

Name of dredge.	Test Number.	Tangential velocity of water at periphery of runner, in feet per second. w	Tangential velocity of water at cut-off lip at outlet of casing, in feet per second. w_1	Mean velocity of water in discharge pipe, in feet per second. w_2	Head lost by portion of the water, in feet. $\frac{w_1^2 - w_2^2}{2g}$	Mean radius of casing at outlet, which would give mean velocity of discharge pipe, in feet.	Remarks.
Gamma..	1	21.33	21.33	13.76	4.13	4.46	If lip be removed, w_1 becomes 18.2 ft. and loss of head becomes 2.2 ft.
Delta. ...	3	41.77	39.83	17.02	20.00	8.60	If lip be removed, w_1 becomes 36.5 ft. and loss of head becomes 16.2 ft.
Epsilon..	2	40.45	32.34	20.90	9.45	5.56	
Iota	3	44.55	34.81	18.18	13.70	7.70	
Kappa...	5	41.65	38.10	21.40	15.40	6.81	

NOTE: There are three ways of diminishing the loss of head attending the change of velocity from w to w_2; (1) as in the case of the *Gamma's* pump, great recurvature of the vanes will enable some of the velocity head to be converted into pressure; (2) the casing may be made large enough to allow the water to whirl in a free vortex until the desired velocity is obtained at the outlet; and (3) the outlet opening may be small, and a pipe fixed thereto which enlarges in area gradually until the area is that of the pipe. A combination of the three methods is recommended in ordinary practice.

The writer desires to ask Mr. Maltby why it is that the gauge readings shown upon the pump drawings (Plates 36-40 of Mississippi River Commission Report) do not correspond with any of the experiments referred to on page 156 of said report, referring particularly to the "Delivery Head" in Column 8.*

In the writer's previous communication he questioned the accuracy of the common expression, $\frac{w\ V}{g}$, for the head imparted to the water by the runner of a centrifugal pump, because it was not clear, at first sight, that this expression would be the correct one for the sum of the velocity head and the pressure head possessed by the water leaving the runner. The step in the reasoning which seemed to him to be doubtful was where the change of angular momentum of the water per second was multiplied by the angular velocity of the runner, and the product called the work done per second. However, he thinks that since he wrote he has seen how the intermediate steps in the reasoning can be supplied and the expression, $\frac{w\ V}{g}$,

* Note by Editor.—This communication was received before, and presented to, the Congress. What follows was sent by Mr. Higgins a month later.

Mr. Higgins. established. Possibly, to many persons, no intermediate steps in reasoning are necessary; but, to the writer, it seems a long jump from the familiar proof of the equation

$$m\,l\,.\,\delta\,v = p\,l\,.\,\delta\,t.$$

(where a force, p, acts at the center of gravity of a body of mass, m, at distance, l, from a fixed point, producing an increment in velocity, $\delta\,v$, at right angles to l in time $\delta\,t$) to the statement that, when a rotating wheel causes angular acceleration and other motion in a mass of water, the angular velocities of wheel and water being different, the angular impulse of the wheel is equal to the change of angular momentum of the water.

For instance, if the smaller of two solid wheels, A, whose radius is R_A, has a force, P, applied to its rim, and this force is transmitted to the rim of the larger wheel, B, whose radius is R_B, both wheels being free to rotate about fixed axes, then, neglecting friction and the weight of A, and confining our attention to the effect of P in producing acceleration in the rim of B, which weighs W lb., we have, at the end of a second, an angular velocity, $-\varpi$, in A and $\varpi \frac{R_A}{R_B}$ in B. The change of angular momentum of B is $\frac{W}{g}\,.\,\varpi\,\frac{R_A}{R_B}\,.\,R_B\,.\,R_B$ $= \frac{W}{g}\,R_A\,.\,R_B\,.\,\varpi =$ angular impulse for 1 sec. on $B = P\,.\,R_B$.

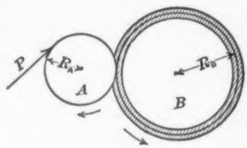


FIG. 48.

This, of course, is not equal to the angular impulse on A, *viz.*, $P\,.\,R_A$.

Nevertheless, the work done per second by P on A is equal to the work done on B per second, *i. e.*,

$$\tfrac{1}{2}\,P \times R_A\,\varpi = \tfrac{1}{2}\,P\,.\,R_B\,\varpi\,\frac{R_A}{R_B}.$$

So here we have an illustration of a case where a rotating driving body, A, causes an angular velocity in another body, B, and while, of course, the work expended is equal to the work done, yet the change of angular momentum of B is not a measure of the angular impulse of A. Now, in some respects, B resembles the mass of water in a centrifugal pump and A resembles the runner. It is excusable, therefore, to ask if it is self-evident that the change of angular momentum in a rotating mass of water is a measure of the angular impulse of a runner which rotates with an angular velocity different from that of the water. The similarity between the two cases is more apparent when, by means of suitable intermediate gearing, B and A rotate about the same axis, but at different rates.

Mr. Higgins.

Another stumbling block is this:

Suppose Fig. 49 represents a runner, and the space between the dotted line and the periphery is just large enough to hold W lb. of water, which is the quantity assumed to leave the runner in 1 sec. Now, during the second in which this particular W lb. leaves the runner, the runner is exerting pressure upon other masses of water, some of which were in it at the commencement of the second considered and some entered during that second. It seems reasonable, then, to ask if it is self-evident that the angular impulse of the runner, during the second considered (which angular impulse is exerted upon other masses of water as well as the W lb. just leaving the runner), is to be measured by the change of angular momentum undergone by the particular W lb. leaving the runner.

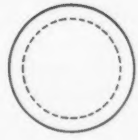


FIG. 49.

To some persons, perhaps, these questions may seem unnecessary. They are mentioned in order to explain how some uncertainty in the writer's mind as to the correct way of answering them led to his error, and he will next explain the answers that have occurred to him.

In the first place, a little consideration shows that the analogy of the solid wheels, A and B, does not hold at all. The angular impulse of A has nothing whatever to do with that of B. It is the force exerted on the rim of B that has to be considered, and its impulse is $P\ R_B$, irrespective of what diameter A may have or whether or not A be a wheel at all. Further, the acceleration undergone by a band containing W lb. of water in a runner of a centrifugal pump is not merely angular, but partly radial also, because the band expands in diameter as it moves.

Secondly, in Fig. 50, let the concentric spaces in the runner, *viz.*, 1, 2, 3 ... n, be each capable of containing W lb. of water, W being the weight that leaves the runner in one second.

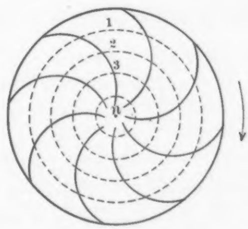


FIG. 50.

During one second, the contents of Space 1 will be discharged from the periphery, and the effect of the pressure of the vanes upon them will be a certain change of angular momentum. During the same second, the contents of Space 2 will enter and occupy Space 1, and the effect of the pressure of the vanes on these particles will be exactly the same as that produced in the previous second on the W lb. now leaving Space 1. Similarly, the contents of the Spaces 3, 4 ... n, undergo accelerations equal to those undergone during pre-

Mr. Higgins. vious seconds by the W lb. now leaving the runner. Each particle takes n sec. to pass through the runner. Therefore, the total acceleration undergone by any W lb. which have passed through the runner is equal to that imparted by the runner, during 1 sec., to all the water within, or entering, the runner during that second. So, in estimating the energy possessed by the W lb. leaving the runner during any second, we may consider that energy equal to the work done on all the particles within, or entering, the runner during that second, that is, the work done by the runner per second.

The pressure exerted by each vane on the water passing in front of it will have a resultant at a radius, z. The resultant pressures of all the vanes will act at points lying on a circle whose radius is z. If P denote the sum of the pressures exerted by all the N vanes, $\frac{P}{N}$ will be the total pressure exerted by one vane. Let x be the perpendicular distance of the line of action of $\frac{P}{N}$ from the center of the runner. Then the angular impulse per second of that vane $= \frac{P}{N} x$.

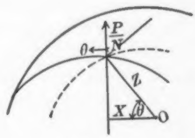


FIG. 51.

Let θ denote the angle between the direction of $\frac{P}{N}$ and the direction of motion of the point where the resultant pressure acts. This direction of motion is tangential to a circle, concentric with the runner. Then the resolved part of $\frac{P}{N}$ in the direction of motion of the said point of action of the resultant $= \frac{P}{N} \cos. \theta$.

Now $x = z \cos. \theta$

$\therefore$ the angular impulse of the vane per second

$$= \frac{P}{N} z \cos. \theta$$

= product of the tangential resolved part of the resultant pressure into the radius, z.

The total angular impulse of the whole runner, therefore, per sec.,

$$= P \cos. \theta \times z.$$

Although this angular impulse is not acting upon one and the same mass of water during the second, yet, as shown above, the equivalent of this angular impulse will be the total angular momentum possessed by the W lb. of water which leave the runner per second.

If v be the absolute velocity of each particle of water as it leaves

the runner, and y the perpendicular distance of the direction of v from the center, then the change of angular momentum in the W lb. leaving during a second Mr. Higgins.

$$= \frac{W}{g} v\,y = \frac{W}{g}\,w\,R$$

where W is the tangential component of v.

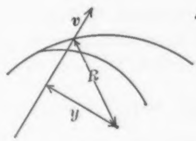


FIG. 52.

We have, therefore, for one sec.,

Total angular impulse = total change of angular momentum, *i.e.*,

$$P \cos.\,\theta \times z = \frac{W}{g}\,w\,R.$$

The work done per sec.

$$= P \cos.\,\theta \times z \times \varpi = \frac{W}{g}\,w\,R\,\varpi = \frac{W}{g}\,w\,V.$$

A few remarks may be made on this result:

1.—The expression, $\frac{w\,V}{g}$, represents the energy possessed by each pound of water as it leaves the runner, or, rather, the total energy which has been imparted to each pound by the runner, for, in practice, the energy possessed will be less than the energy imparted by a certain amount which is lost through friction. This, however, we need not consider at present. Now, if the energy of a rotating mass of fluid be simply due to the motion which has been imparted to it, one might expect that any expression for that energy would be in terms of the fluid motion only, and would not involve the velocity of the body which caused that motion. To some persons an explanation of the reason for V, appearing in the above expression, may appear necessary, because it is conceivable that the same amount of energy as that possessed by the rotating mass of water could have been communicated to it by quite other means.

Let us consider the action of a vane on the water in front of it. In a frictionless fluid, the pressure between vane and water will be normal to the vane. The pressure at each point of a vane may be resolved into its rectangular components, radially and tangentially. Each component will do its share of work on the water passing the point. The radial component causes acceleration and does work in a radial direction. The tangential component causes the rotary motion in the water. [At present, for the sake of simplicity, it is assumed that the water moves outward from the center of the runner in expanding bands, and that each particle, on arriving at a certain distance from the center, will possess a velocity and pressure which will depend upon its distance from the center only. Later on, the effect of deviation from this steady kind of motion will be

Mr. Higgins. considered.] Now, in consequence of its rotary motion, each particle will exert its centrifugal force on the particles outside it, and the total head, caused by the sum of all such forces, is to be found by integration. Centrifugal force tends to cause radial acceleration. If the vanes are radial, the radial components of their pressures $= 0$. Therefore, in such a case, the only cause of the outward flow is centrifugal force. Again, when the vanes are radial, the angular velocity of the water is uniform, and it can be shown that the head, or energy per pound, arising from centrifugal force, is $\frac{w^2}{2g}$, where w is the tangential component of the velocity at the periphery. If u denote the radial component of the velocity at the periphery, then the corresponding kinetic energy per pound $= \frac{u^2}{2g}$, and, therefore, the pressure, arising from centrifugal force (which corresponds to potential energy) $= \frac{w^2 - u^2}{2g}$ per pound of water. This is all the potential energy which a runner with radial vanes imparts to each pound of water. Now, if v is the actual velocity of each particle of water, as it leaves the periphery, the kinetic energy per pound $= \frac{v^2}{2g} = \frac{w^2 + u^2}{2g}$. So that the total energy imparted to each pound of water by a runner with radial vanes $= \frac{w^2}{g} = \frac{V^2}{g}$, because V (the tangential velocity of the runner is in this case) $= w$.

With radial vanes, therefore, the formula seems correct. When we come to deal with runners in which the vanes are curved backward, we find that, in addition to centrifugal force, there is also the outward thrust of the vanes tending to accelerate the water radially. Compare two runners, one with radial vanes and the other with backward curved ones, and suppose their speeds adjusted so that w and u, and, consequently, their resultant, v, are the same at the periphery of each. The kinetic energy per pound, *viz.*, $\frac{v^2}{2g}$, is the same in each case. Let us suppose that the backward curved vanes are so shaped that the angular velocity of the water is uniform in the runner containing them. [This is not necessarily equal to the angular velocity of the water in the runner with radial vanes. The angular velocity will be $\frac{w}{R}$, where R is the radius of the runner, and R may have different values in the two cases.] In both cases, the energy per pound due to centrifugal force will be $\frac{w^2}{2g}$. But, in the

case of the runner with curved vanes, part of the radial velocity will be due to the radial components of the pressures of the vanes; therefore, we cannot now say that the potential energy per pound is $\frac{w^2 - u^2}{2g}$. The potential energy will be greater than that. It does not appear to be easy to prove in any particular case that the difference in potential energy is represented by Mr. Higgins.

$$\frac{wV}{g} - \frac{w^2}{g};$$

but we may see the reasonableness of the proposition, as follows: The radial acceleration caused by the vanes, being zero when there is no backward curvature, will increase with the amount of backward curvature up to a certain point. The greater the backward curvature, the greater must V be made in order to give a certain value for w. Now, when the radial acceleration caused by the vanes increases, that caused by centrifugal force diminishes; consequently, the potential energy per pound, represented by pressure arising from centrifugal force, increases. In other words, the total energy increases with V.

The latter part of the foregoing argument may be made clearer by remembering that u consists of two parts, *viz.*, u_r, caused by the radial pressure of the vanes, and u_c, caused by the centrifugal forces. The total head caused by centrifugal forces $= \frac{w^2}{2g}$, and, as $\frac{u_c^2}{2g}$ of this is velocity head, the pressure head $= \frac{w^2 - u_c^2}{2g}$. Now, the larger u_r is, the smaller is u_c, and, therefore, the pressure head is larger.

It was said above that the radial acceleration caused by the vanes will increase with the amount of backward curvature up to a certain point. The qualification of statement here refers to the case where a vane curves backward so much toward the outer end that the radial acceleration, already imparted by vane pressures nearer the center and by centrifugal forces, causes the water to leave the face of the vane before the periphery is reached.

2.—Referring to Fig. 51, it may be remarked, in passing, that the direction of the resultant pressure, $\frac{P}{N}$, on a vane is not necessarily normal to the vane at the point where it acts, although, as the liquid is assumed to be frictionless, each element of pressure is normal to the vane at the point of its application. Further, the direction of motion of any particle in contact with a vane is not generally normal to the vane, but is determined by the accelerations previously communicated to it, and by the degree of confinement imposed upon

Mr. Higgins. the water in the runner by the water in the casing outside the periphery. This confinement must be recognized, although it introduces the conception of fluid friction.

3.—It is interesting to compare the effect of angular acceleration of a liquid with that of a solid, because, although, in a solid body, centrifugal force exists, yet it does no work, and there is nothing analogous to fluid pressure; and, as fluid pressure is equivalent to potential energy, it can be inferred that the energy possessed by a band of water of given weight, leaving a runner with given angular momentum, will be greater than that of a solid ring of the same weight, possessing the same angular momentum. Suppose the rim of a wheel to weigh W lb., the weight of the remainder of the wheel being negligible, and let a tangential force, P, act at the center of gravity of a cross-section of the ring. Let w be the tangential velocity of the ring at the end of 1 sec., the ring having started from rest at the beginning of the second, then the change of angular momentum $= \frac{W}{g} w R$, and this is equal to the angular impulse, $P R$. But the distance traveled by each point on the rim $= \frac{1}{2} v$. Therefore, the work done =

$$\tfrac{1}{2} P R \omega = \tfrac{1}{2} \frac{W}{g} w R \omega = \tfrac{1}{2} \frac{W}{g} w V = \tfrac{1}{2} \frac{W}{g} w^2.$$

Now, as previously found, the work done in imparting the change of angular momentum, $\frac{W}{g} w R$, to the W lb. of water which leave the runner in a second $= \frac{W}{g} w V$ or twice that in the case of the solid. The water, accelerated in this way, starts from rest at the center of the runner, and receives the said acceleration in n sec. (see Fig. 50).

Of course, a hollow ring, say, of metal, full of water, which has no motion relatively to the ring, would have its water accelerated in exactly the same manner as if the whole ring were solid. The difference between this case and the case of the water leaving the runner of a centrifugal pump lies in the fact that the pump is continually accelerating fresh particles of water and discharging them when they possess a certain angular momentum and pressure. W lb., leaving the runner in this way, as an expanding band, are under a pressure arising from the centrifugal force of all the particles between the band and the center, whereas the particles in the hollow metal ring have only their own centrifugal forces to cause increase of pressure toward the outer circumference. Seeing that there is a tendency to form a vacuum at the inner circumference of the ring, there will be no gain of pressure on the whole; it is not as though all the particles had communicated to them the pressure existing in the outermost layers.

4.—Let us now consider the probable accuracy of our assumption that the water leaves the runner at all points of the periphery with the same velocity and pressure. If the runner were discharging freely into space instead of into a casing containing water under pressure and in a state of whirl, then the stream between each pair of vanes would tend to lie close to the driving faces of the vanes and to leave the reverse faces. When the outlet is obstructed by a whirling mass of water under pressure, there will still be the tendency for the streams to keep closely in touch with the driving faces of the vanes and to leave eddies or dead water in the other portions of the passages. It seems evident that in actual centrifugal pumps, delivering water, the velocity of the water which issues from the periphery will not be uniform, but will be greatest in the layers close to the driving faces of the vanes. There will be little or no velocity relatively to the vanes near the backs of the vanes. The result will be that the mean velocity, radially, of the particles which issue from the runner will be greater than that assumed. Fig. 54 is a diagram of velocities plotted from the result of Experiment No. 2 with the *Epsilon's* pump. The assumed radial velocity, $u = 8.53$, is shown in a full line, also the velocity, $V = 49.66$, which the runner has at its periphery. The deduced velocities, w, v, and v_r, are also plotted in full lines, $w = 40.45$, being the tangential velocity of the water, v, the actual velocity of the water, and v_r the velocity relatively to the vanes. Consider what will be the result if the mean radial velocity is double that corresponding to uniform flow. The dotted diagram shows how the various components of the velocities of the water change. It will be noticed that v is lessened by 5.6 ft. per sec., and that w is lessened by 9.4 ft. per sec. Mr. Higgins.

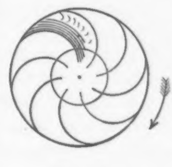


FIG. 53.

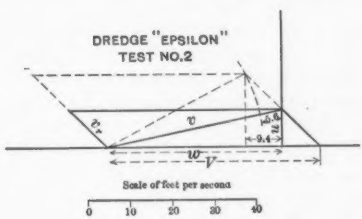


FIG. 54.

This seems to the writer to indicate why, in Mr. Maltby's experiments, the horse power, calculated on the assumption that $\frac{w\,V}{g}$ represented the work done per lb. of water, was found to be generally greater than the indicated horse power; for the kinetic energy $= \frac{v^2}{2g}$

Mr. Higgins. per lb. of water, and the potential energy depends upon w^2, and both of these are lessened if the radial flow be not uniform. This means that the runner does not really impart the change of angular momentum, $\frac{W}{g} w R$ per sec., but a smaller quantity.

Some laborious research lies before those who will succeed in establishing a reliable formula for the work done by the runners of centrifugal pumps. In the meantime, such experiments, as the writer has been able to examine, seem to show that a fair approximation to the power required to drive a centrifugal pump is arrived at when it is assumed that the theoretical energy per pound of water $= \frac{w^2}{g}$.

Mr. Venable. WILLIAM MAYO VENABLE, ASSOC. M. AM. SOC. C. E., New York City. (By letter.)—Mr. Maltby's paper is exceedingly interesting and valuable because it contains much data that are not readily obtainable. The expense of conducting tests such as those carried on by the Mississippi River Commission is so great as to place such work out of reach of most investigators. The field of the paper is broad, there being many engineering problems connected with the subject of dredges that have little to do with the actual construction of the pumping machinery. It is with the latter that the present writer is chiefly interested, and he confines his discussion of this paper to that part of it which deals with the centrifugal pumps as pumps, and not as devices for moving sand.

The writer does not think that the conclusions reached by Mr. Maltby, as to the efficiency and relative merits of these pumps, are justified by the data given in his paper, or that the theories advanced, regarding the manner in which the useful work to be credited to the pump should be measured, are correct.

It appears to the writer that Equation 1 on page 406 is not justified theoretically, and that it is not sufficiently close to the truth, when applied practically, to sanction its use; and the writer presents here his reasons for differing with this equation, first, on theoretical grounds, and, second, on practical grounds.

If the velocity of water in the pipes at the pressure developed by the pumps were absolutely steady, and if piezometer tubes were inserted into the centers of the pipes and turned so as to present orifices facing the direction of the current on both the suction side and the discharge side of the pump, as in Fig. 55, the difference in the readings of gauges attached to these two piezometer tubes referred to the same zero would be the actual total head developed by the pump, for it would be the sum of the velocity head and the pressure head on the discharge side, less the sum of the velocity head and pressure head on the suction side, with no disturbing

Mr. Venable.

cause but the pump between; but where piezometer tubes are placed parallel to the flow at the outside boundary of the pipe, they measure the pressure at that point, which is not the same as the pressure in the center of the tube, and is not the same as the mean pressure throughout the stream. It is not permissible to take a measurement

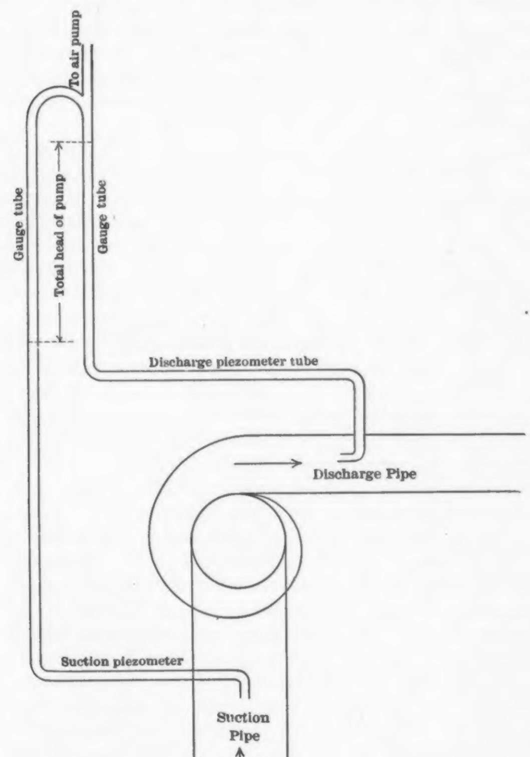


FIG. 55.

of pressure at that location and add to it the mean velocity head or, more correctly speaking, the head corresponding to the mean velocity. Neither will the readings taken with piezometer tubes so located, even if the very greatest care is taken to make the orifices normal to the direction of the stream, or to make them so small that

Mr. Venable. disturbing influences will be eliminated, be sufficiently accurate if the pump produces pulsating or fluctuating pressures and velocities, such as are produced by centrifugal pumps. The error that will arise from such pulsations will depend partly upon the frequency of pulsations of the pumps themselves and partly upon the length of the column of water against which they act (in the case of these dredges, the length of the discharge pipe), and partly upon the elasticity of the walls of the discharge pipe, or the air cushion interposed between the pump and the discharge pipe, if there is any. In the cases where the velocity head is a very considerable portion of the total head produced by the pump, the error due to these causes may be very great.

Bernouilli's theorem applies to water in pipes where there is head lost in friction, as well as to those where there is no friction, if it is corrected to allow for the friction head lost. Such a correction is very difficult to make in the case of pipes of varying form, but it is not difficult in the case of straight-line flow where the friction acts against the motion of every stream. In this case, the case of a stream in a smooth, straight pipe, the friction head in any given length of the stream is the same for every element or streamlet, consequently the sum of the velocity head and the pressure head must be equal at each point across the section of a straight pipe. (The condition, of course, that the points considered are distant from the ends of the pipe or from elbows and bends is assumed. If this distance is many times the diameter of the pipe, the condition of straight-line flow is fulfilled.)

As Mr. Maltby measured the pressure at the surface of the pipe, his formula, which assumes that the pressure head at that point can be taken as the total pressure head and added to the velocity head to obtain the total head, is inaccurate. The error of that assumption would be very small in the case of pumps developing very high pressures and forcing water through pipes at low velocities, but it appears to the writer that the velocities produced in the discharge pipes of dredges are so high that the differences in pressure throughout the cross-section of the stream within the pipe cannot be ignored.

Moreover, it is not legitimate to use the square of the mean velocity of the streamlets instead of the mean of the squares of the velocities of the streamlets in determining the mean velocity head in the pipe.

Referring to the diagrams given in the paper on the flow of water in pipes, by Messrs. Williams, Hubbell and Fenkell,* for $16\frac{5}{16}$-in. pipe, and to Traverse No. 93, it will be seen that, in the experiments there reported, the velocity as near to the pipe surface as it can be measured was only 1 ft. per sec., while the velocity near the center of the

* *Transactions*, Am. Soc. C. E., Vol. XLVII, Plate IV.

pipe was 7.75 ft. per sec. These experiments indicate that the Mr Venable. actual velocity of the water where it is in contact with the wall of the pipe is zero, and this must be the case theoretically, provided there is adhesion between the water and the material forming the pipe. Other experiments recorded in the discussion* of that valuable paper indicate the same thing, although in these other experiments measurements are not shown as close to the bounding surface of the pipe as in the experiments by Messrs. Williams, Hubbell and Fenkell. Now, if the pipe were perfectly smooth and straight and the piezometer tube had an opening indefinitely small at the surface and normal thereto, the velocity of the water at the surface being zero, the reading of such a piezometer would be the same as that of a piezometer placed as in Fig. 55, but it is impossible to obtain a perfectly smooth tube of considerable length, and it is impossible to make a piezometer with an opening indefinitely small, and, in consequence, the reading of the piezometer is of a pressure head less than that which exists between the surface of the pipe and the water, for the reason that the effective opening of the tube is projected a short distance into the stream because of the roughness of the pipe and the size of the opening.

All the measurements in the paper on the flow of water in pipes just referred to are concerned with velocities much slower than those dealt with by Mr. Maltby, but it is evident from the data given in that paper that the effect of increasing the mean velocity is to make the changes in velocity near the surface of the pipe much more sudden than in the cases where the velocity is slow.

That the pressure increases as the velocity diminishes in the same chamber may be seen qualitatively from the diagrams in Fig. 37 on page 441 of Mr. Maltby's paper, and other diagrams. In that diagram is plotted a line showing the readings of piezometer tubes connected at various points in the casing of the pump from the center out, and the diagram very clearly shows that the pressure in the casing increases from the center to the circumference; that it is greatest at the circumference and not at the ends of the vanes where the velocity is greatest. At the circumference of the vortex chamber in molecular contact with the iron the velocity of the water is zero, and there the pressure is maximum. The same principle holds in a straight pipe where friction causes the difference in velocity between the center and the periphery, as in a pump where friction and change of section in the water channel combine to reduce the velocity.

On page 407 Mr. Maltby refers to a paper by Mr. W. M. White,† and, again, on page 420 he refers to a subsequent paper by the same writer giving experiments illustrating in a very lucid manner the

* M. Bazin, p. 249, on 31½-in. pipe, and Mr. Cole, pp. 279 and 281.

†*Journal of the Association of Engineering Societies*, October, 1900.

Mr. Venable. principles involved in the Pitot tube. This second paper of Mr. White is a valuable contribution to hydraulics in that it presents to the eye certain well-established principles regarding the conversion of velocity head into pressure head, and *vice versa;* but Mr. White's first paper does not appear to the present writer to be correct. Mr. White describes a velocity gauge depending upon Bernouilli's theorem, neglecting friction. The investigation is defective from a theoretical point of view, because it neglects entry head, a form of friction head due to the abrupt change in the bounding service of the stream where it enters the pipe, which is equal to about one-half of the velocity head, as ordinarily calculated. Mr. White has developed a theory, and corrected his formula to allow for entry head, on the assumption that the entry head is 50% of the velocity head. He has assumed that he has measured the velocity head, and without giving any experimental verification of this in his paper, he has applied his theoretical results to correcting the actual readings of current meters which do not agree with his tubes. A more logical way of proceeding, under the circumstances, in developing a new theory or proposing a new type of instrument, would have been to calibrate his current meters carefully, and use them for verifying his new device. The factor which Mr. White actually did measure, or, more correctly speaking, the reason that he got readings upon his velocity meter to correspond somewhat, when corrected, to the actual velocity head, was the fact that the entry head caused a difference of static pressure between the suction basin and the point where his tube was inserted. The writer wishes to make it perfectly clear that there is no such error in Mr. White's investigations of the Pitot tube, so far as he is aware, but that he takes exception only to the meter described by Mr. White, which consists of a piezometer tube placed normal to the direction of the flow. It should be remarked, however, that since the entry head is a function of the velocity, there is a certain value attached to these measurements, although the reasoning given in Mr. White's paper is not correct. This same error, or a similar error, is inherent in the passages quoted from Professor Gregory's report on pages 405 407 and 406 408. Professor Gregory assumes several impossible things, makes a theoretical assumption where there is a theoretically indeterminate quantity, and derives a result that is directly contrary to the well-established laws of hydraulics. In the first place, he assumes a frictionless tube with a stream of water flowing through it with a uniform velocity (which must be in a frictionless tube), every particle moving at the same speed and in the same direction; then he places square ends upon this tube communicating with two chambers, and assumes that the tube is still frictionless from a hydraulic point of view, totally neglecting the fact that there must

be entry head and emergence head at these openings, and that entry head and emergence head are of precisely the same nature as friction head, that is, that they are caused by changes in the velocity of the particles of water with reference to one another. But if we approach the ideal sought by Professor Gregory by making the tube as smooth as possible, and eliminate the entry head given, making the form of opening (in Fig. 19) so that the entry head is reduced to some 3% of the velocity head at X, and if we still further reduce the emergence head by smoothing the openings from the tube into the chamber L, and then if we divide the tube into two parts at X, and separate the parts so that a jet of water passes from K to L, the surface of the water in K being at A, and the surface of the water in L being at E, we have the device illustrated in Professor Unwin's article on Hydro-Mechanics in the Encyclopedia Britannica (a figure with which we are all familiar), in which the velocity at X is shown to be, with theoretically perfect passages, due to the total head from the surface, A, to the tube, $M\ N$. Professor Unwin states that experiments show that the head, $B\ E$, may be reduced to as little as 3% of the velocity head at X, while Professor Gregory makes the velocity head at X equal to the pressure head, $B\ E$. This investigation of Professor Gregory is like that of Mr. White; it is theoretical only and not backed up by any experiments. As a matter of fact, an ideal theoretical investigation would show that if the tube were perfectly smooth, and so formed that there would be no friction head consumed by the water passing through it at any velocity, the water at the elevation, $A\ B$, in the tanks, K and L, might be passing through the tube at any velocity whatever, and there might be any velocity head at X, because the head required to produce that velocity in the water as it passes from K to L would be exactly equal to the head restored to the water by that velocity in the other tank. Professor Gregory's reasoning would only hold in the case where there was no entry head and where the emergence head in L was entirely dissipated, and that also is an impossible case, as has been shown in Appendix I of the writer's paper, "The Principles of Design of Velocity Pumps," presented to this Congress, and which was verified qualitatively by experiments. **Mr. Venable.**

Referring again to Mr. Maltby's paper, it is evident that this error in theory alone does not greatly vitiate his conclusions as drawn from the data in Table 33, as the velocity calculated in the suction side is almost equal to that on the discharge side in most of the tests, so that practically the two errors offset one another in Formula 1. We now come to the practical objection to the use of piezometer tubes located as shown, to measure heads developed by centrifugal pumps, which is this: such pumps do not develop uniformly steady heads or velocities. They develop pulsating heads and

Mr. Venable. velocities, as described in the writer's paper before referred to, and these pulsations are the chief source of difficulty in measuring the heads and velocities produced by such pumps by the use of tubes. Attention has been called to this in Appendix II of the writer's paper, but as the case has not been proven mathematically in that Appendix, and as experiments have not been made to determine qualitatively the effect of known pulsations upon the readings of gauges in long, straight pipes, attention is called to the remarks of Gardner S. Williams, M. Am. Soc. C. E., in his paper on "Turbines and Water Wheels," presented before the Congress. He says:

"The effect of a vibrating stream of water acting along a surface containing an orifice is to cause a gauge attached thereto to read high on account of the continued series of blows delivered to it by the vibrations of the water."

The writer refers again to the paper of Mr. W. M. White,* in which he asserts that "The Pitot tube was found to give a higher velocity than existed."

But it is not necessary to go outside of the data given in Mr. Maltby's paper to show that there must be some such effect in the case of the pumps on the Dredge *Zeta*. The data for the following discussion are contained in Table 33.

The *Zeta* discharged through a pipe 32 in. in diameter and 1 092 ft. long. The friction head calculated in it, according to Weisbach's formula, for the various mean velocities given by Mr. Maltby, is given in Table 41, and shows how this corresponds with the head indicated by the tubes. Were there no error in the gauges due to pulsations, we should expect that these calculated heads would differ from the indicated heads by almost the same amount in the case of each of the three runners tested, as the pipe was the same; but such was not the case. It is immaterial for comparison only whether Weisbach's formula can be applied to the case in question, but it is worthy of note that the tubes indicate from 10 to 32% more head lost in friction than the formula would predict, assuming that the pipe is submerged at its discharge end, and that the velocity head is all lost, as indicated in Plate XXXVII of Mr. Maltby's paper. Unfortunately, the speeds of the engine in the several tests with different runners do not correspond sufficiently to permit a complete study of the comparative merits of the different runners, but a few readings at approximately the same speed may be compared, and these bear out the statement, regarding the relation of the number of vanes to the head, in the writer's paper on pumping machinery; but Mr. Maltby's conclusions regarding the relative efficiency of the runners are erroneous, because the piezo-

* *Journal of Association of Engineering Societies*, Vol. XXV, p. 63.

meter readings credit the poorest pump with the greatest head. Mr. Venable.

If we neglect these readings, and make a comparison of the pumps upon the assumption that the velocity in the discharge pipes was measured correctly with the Pitot tubes, which is a fair assumption, as the work appears to have been very carefully done, the difference between the real efficiencies of the runners becomes apparent. The velocities are almost uniform, because the discharge pipe is 1 000 ft. long and the water in it of such inertia that it could not respond to rapid pulsations to any great extent.

For the purpose of an approximate comparison, we may assume that where velocities do not greatly differ, the friction heads are proportional to the squares of the velocities, and, since the quantities of water pumped are directly proportional to the velocities, the useful work is proportional to the cubes of the velocities. Let us select the following readings from Mr. Maltby's table in which the pumps were run at approximately the same speeds with different numbers of blades in the runners, and calculate the cubes of the mean velocities there observed:

Runner.	Revolutions per minute.	Mean velocity discharge, in feet per second.	(Mean velocity discharge)^3.	Indicated horse-power.
3-blade................	180	15.8	3 944	640.9
7-blade.................	180	17.9	5 735	770.1

The ratio of efficiency of the 3-bladed runner to that of the 7-bladed runner would, therefore, be

$$\frac{3\,944 \times 770}{5\,735 \times 641} = 82.6 \text{ per cent.}$$

Again we select:

Runner.	Revolutions per minute.	Mean velocity discharge, in feet per second.	(Mean velocity discharge)^3.	Indicated horse-power.
5-blade.................	170	16.3	4330	690
7-blade.................	170	17.0	4913	665

The ratio of the efficiencies in this case is

$$\frac{4\,330 \times 665}{4\,913 \times 690} = 85 \text{ per cent.}$$

Mr. Venable. Taking other examples, we have:

Runner.	Revolutions per minute.	Mean velocity discharge, in feet per second.	(Mean velocity discharge)^3.	Indicated horse-power.
5-blade	175	16.4	4 410	734
7-blade	175	17.4	5 268	703.5
3-blade	169	15.0	3 375	524
7-blade	168	17.0	4 913	639

The ratio of efficiencies in these cases are 80 and 84%, respectively.

Between the 5-bladed runner and the 3-bladed runner there seems to be little choice, and these tests apparently bear out Mr. Maltby's remark that the capacity, not the efficiency, is reduced by having fewer blades, but there is a very apparent advantage to the 7-bladed pump by both methods of comparison; that is, by comparing with the calculated predictions of Weisbach's formula and by the method just used; but if we refer to Fig. 35 of Mr. Maltby's paper, where the outline of the runners is given, it will be seen that the vanes of the 3-bladed pump and 7-bladed pump are alike, while those of the 5-bladed pump are different, and this is sufficient to account for the poor showing of the 5-bladed pump in comparison with the others. Had the vanes in this pump been like those in the other two pumps, it would doubtless have shown an efficiency intermediate between that shown by the 3-bladed runner and the 7-bladed runner.

TABLE 41.

	Revolutions per minute.	Mean velocity in discharge pipe.	Delivery head indicated by tubes.	Friction head calculated by Weisbach's formula	Difference.	Percentage of difference.
Zeta.						
3-blade ..	178	15.735	33.86	29.38	4.48	15
	180	15.76	34.65	29.40	5.25	18
	180	15.87	35.02	29.70	5.31	18
	176	15.11	32.14	27.25	4.89	18
	169	14.96	31.58	27.01	4.57	17
5-blade ..	150	14.15	29.81	24.10	5.71	23.7
	159	15.0	33.75	27.01	5.74	21.3
	170	16.35	39.60	31.8	7.8	24.5
	171	16.43	42.29	31.9	10.4	32.7
	175	16.48	40.16	32.19	7.97	25
7-blade ..	180	17.49	40.73	35.97	4.76	13
	180	17.96	41.83	37.75	4.08	10.8
	168	16.96	37.35	34	3.35	10
	170	17.06	38.22	34.1	4.12	10.8
	161	16.09	34.46	30.40	4.06	13
	180	17.56	41.03	36.19	4.84	13.31
	175	17.38	39.17	35.53	3.64	10.3

The writer has entered upon this discussion because of a keen interest in the problems suggested by the paper and their bearing upon the practical design of centrifugal pumps for various purposes. It appears to him that the pump on the *Zeta* is credited with from 5 to 10% higher efficiency with the 7-bladed runner than it should be credited with, and that with the other runners it is credited with from 25 to 30% too high an efficiency. The writer has not had time to look into the data given in connection with the tests of the other pumps, but it seems probable that the same kind of errors exists in the calculations of efficiencies credited to these pumps. Several of these pumps are very excellent for the purpose for which they are designed. The fact that the efficiencies do not go as high as indicated in Table 33, does not show that the pumps do not compare very advantageously with the best of centrifugal pumps met with in practice, when the basis of comparison of all the pumps is strict and fair. **Mr. Venable.**

C. W. STURTEVANT, M. AM. SOC. C. E., Scranton, Miss.—The speaker would like to relate an incident showing the necessity of mathematical refinement in regard to the shape of runners and casings of centrifugal dredging pumps. **Mr. Sturtevant.**

On this occasion the foreman, who placed a new runner in the pump on Sunday while making other repairs, did not notice that the machine shop had bored the tapered hole in the hub from the wrong side. The runner was put in place with the wrong side next the engine, and the blades, instead of curving gracefully backward as the runner revolved, turned abruptly to the front in direct opposition to all theoretical curves. The pump was run under these conditions during the week without attracting particular attention. The next Sunday the error was discovered while replacing liner bolts.

It would seem that the theoretical shape of runners and casings is not so important a factor in removing the greatest number of yards of material for the least money as a plain, practical shape that can be quickly and cheaply repaired by unskilled labor.

In estimating the cost per yard of material removed on the Mississippi River, in what way is the yardage calculated? Some time ago the speaker was with the Mississippi River Commission, and there were some reports concerning cost per yard of material removed, but the area from which the calculations were made was 800 ft. in width, while the actual dredged channel was only 100 or 150 ft. in width. In many of these places the yardage removed was more than the entire fleet could have removed in the same time. The current, after being started by the first dredged cut, removed probably ten times as much material as the dredge.

Therefore, it is not fair to use all the material removed from this 800-ft. area, by the dredge and current combined, in making an

Mr. Sturtevant. estimate of the cost of dredging by the yard, and to use that price as a basis for estimating dredging elsewhere, as in harbors, canals, or sluggish streams. On account of such misleading comparisons, it is often thought that contractors are bidding high prices for work. If a contractor does the dredging on the Mississippi River he does not receive pay for a single yard outside the actual cross-section of the channel as first staked out.

The Engineer Reports of the Mississippi River Commission contain published data as to the exact cost of all renewals, care of plant and operations, each in its separate place in the reports. But the cost cannot be applied to yardage. The cubic yard as a basis of cost cannot be used in dredging on the Mississippi River, because there is no way to determine the yardage removed by the dredge.

If these different costs were combined they would show the total cost of opening the channels to a certain depth, but they would not show the cost per yard of material removed by the dredge.

If the cut is not properly located, all the dredging possible will not open a channel, and the dredge may have to be removed to prevent grounding.

The general idea that dredging can be done so cheaply is a mistaken one. In one paper submitted to this Congress reports of cost per yard are appended. Only the actual running expenses during the short period selected out of the year's work are given, and no mention is made of the cost of extended repairs to machinery, of dockage of boat which is necessary each year, or of cost of moving plant from place to place, all of which must be added to the cost given in the paper. Neither does the cost given include the interest on the investment in the plant, insurance, taxes, or damage suits which the contractor must allow for in his estimates of cost.

While a Government dredge can be given credit for each and every yard removed in the vicinity of the channel, a contractor only gets pay for the exact number of yards in the cross-section laid out for dredging, and, in order to insure the channel until accepted by the U. S. Engineers, the cross-section must be overdredged both in depth and width, or else the entire plant may have to be moved back to take out a few yards, causing one or more days' delay.

There is a great fluctuation in prices of dredging due to the variation in material alone. There is no doubt in the speaker's mind that under the most favorable conditions and material, the cost, without profit added, will exceed 5 or 6 cents per yd., and careful compilation of all costs in Government reports will bear out this statement. The speaker knows of dredging that has cost 16 and 17 cents per yd., where the plant used was good and well managed. There have been several contracts taken at prices of from 9 to 15 cents, where the contractors have lost money, and some have gone

into bankruptcy; and this occurred in harbors, canals and slow-running streams, where the amounts dredged could be accurately determined by cross-sections. Mr. Sturtevant.

The speaker would like to make another statement showing the reasons for great differences in prices of dredging work. In one contract, with the same dredge, the same crew, and other conditions being the same, except the material, there were pumped, during a certain period, less than 70 000 cu. yd. During the same length of time in the other material there were pumped 248 000 cu. yd., or $3\frac{1}{2}$ times the quantity dredged during the first period, and what would have been a fair price per yard during the second period would have resulted in serious loss during the first period. The classification of this material under water is often very difficult, and it is only by long experience that a correct judgment can be formed.

Lewis M. Haupt, M. Am. Soc. C. E., Philadelphia, Pa.—The speaker would only add to what Mr. Sturtevant has said in regard to contract prices for dredging that a very complete schedule of prices of various contracts was published not long ago in the *Engineering News*, giving prices ranging from 7 to 40 or 50 cents. He does not know of any instance where dredging has been done for a figure as low as 4 cents on an exposed, open bar, with perhaps the exception of the Mersey Bar. Fifteen cents is certainly low enough, with all risks considered. Prof. Haupt.

William M. Hall, M. Am. Soc. C. E., Parkersburg, W. Va.— There are three questions which the speaker wishes to ask, and he hopes that Mr. Maltby will be kind enough to consider them: Mr. Hall.

1.—What is the cost of one of the Mississippi River suction dredges, completed ready for work?

2.—What is the largest size of stones which it is practicable to move with the dredges on regular dredging work?

3.—As Mr. Maltby is somewhat familiar with the Upper Ohio, the speaker would be glad if he would be kind enough to express an opinion as to whether or not one of the suction dredges would be efficient and economical in moving the Upper Ohio River gravel and sand bars? The Upper Ohio River may be considered as including that part from Pittsburg for 200 or 300 miles down stream, or to the mouth of the Great Kanawha River.

All the dredging on the Ohio for the removal of bars, the deepening of channel, and the construction of locks and dams, has been done by dipper and bucket dredges. The cost of such dredging, in that locality, probably ranges from a minimum of 16 or 20 cents per cu. yd. to a maximum of 35 or 40 cents. There are several reasons which occur to the speaker why the Government should not provide a suction dredge for doing its work in that locality, the principal one, and the one which it is pertinent to discuss here, is that a large part of the material may be too coarse to be economically moved by a dredge of that class.

Mr. Hall. Should it be learned that this is not a serious objection, there are, no doubt, one or two excellent reasons, aside from the mere question of first cost, for providing a suction dredge for the Upper Ohio River work.

As the improvement of this river is one of great importance, and as the questions are practical ones which are liable to arise on many other works, the speaker hopes he is justified in asking them, and trusts they will be discussed.

Prof. Gregory. W. B. GREGORY, ESQ., New Orleans, La.* (By letter.)—The writer was employed by the Mississippi River Commission, in the capacity of Consulting Engineer, during the fall and winter of 1902, and was accountable for the method used in computing the results of tests. In writing a report to the Commission, on the completion of the work, it was not thought necessary or advisable to write a treatise on Hydraulics in general or Centrifugal Pumps in particular, or even an extended discussion of the problems involved. However, attention was called to errors in computing results of previous tests, and this was done in what seemed to the writer the simplest possible way. It is probable that a little more explanation would have made the conclusions more apparent. For the purpose of removing any doubt from the minds of those who may hereafter read this paper and its discussions, the writer wishes to explain in greater detail.

The following is quoted from the writer's report.†

METHOD OF COMPUTING TOTAL WORK OF PUMPS.

"The tests of 1897, made while pumping sand, have been reworked by Mr. Maltby and form a part of his report. These tests as originally published are incorrect, as they credit pumps with the sum of head shown by discharge pressure minus the negative head shown by suction pressure, which includes the velocity head in suction pipe and the computed velocity head in discharge pipe. Now, if suction and discharge pipes were of the same cross-section, the method used in computing tests as reported gives twice the velocity head, and is therefore in error by the amount of the velocity head. As the suction and discharge pipes are usually unequal in sectional area a correction must be made, due to the difference of velocity head at these two sections. This point will be taken up again later.

"Another point is misleading in the report of tests of 1897, although the actual error involved is very small. The various heads are always stated in feet of water. As a matter of fact a mixture of sand and water was pumped, and the heads ought to be measured in feet of liquid pumped—that is, the mixture.

"In some cases, instead of 62.5 lb. per cu. ft., the mixture weighed between 70 and 75 lb. per cu. ft.

* Asst. Prof. of Experimental Eng., Tulane Univ.

† Annual Report of the Mississippi River Commission for 1903, pp. 160 to 167.

"In any case the work done by a pump is equal to $Q \times W \times H$. Prof. Gregory.
where—

Q = volume pumped per unit of time.
W = weight per unit volume of liquid pumped.
H = total head = $h_d - h_s + h' + h''$.
h_d = discharge head, obtained by observing the pressure, p_d, at some point in the discharge pipe, then $h = \frac{p_d}{W}$.
$h_s = \frac{p_s}{W}$ = suction head, obtained at some point in suction pipe by observing the pressure p_s. It includes the velocity head, as will be shown.
h' = difference between velocity heads in discharge and suction pipes.
h'' = difference in level of the two points where discharge and suction pressures are measured.

$$\text{Total work} = Q \times W \times (h_d - h_s + h' + h'') = Q \times W \times \left(\frac{p_d}{W} - \frac{p_s}{W} + h' + h''\right).$$

"It will be seen that nearly all the total head is included in the first two terms of the quantity within the parentheses and that the error arising from computing results when pumping sand due to using the weight of a unit volume of water instead of the weight of unit volume of the mixture only affects the last two terms. In the case of h' it is small enough to neglect and probably so in the case of h''.

"It is to be noted that h_s is always negative in these tests, but both h' and h'' may be positive, negative, or zero, depending on conditions in individual cases. Very little error will therefore be made by using W as the weight per unit volume of water instead of the weight of mixture pumped, and the method of computing results is greatly simplified.

"It will now be shown that the suction pressure includes the velocity head in suction pipe where pressure is measured."

The above will be recognized as practically the same statement as that embodied in Equation 1, given by Mr. Maltby.

The text of the report to the Commission, which follows that given above, has been quoted by Mr. Maltby and therefore will not be given again here.

It has been charged by Mr. Venable that the writer "assumes several impossible things, makes a theoretical assumption where there is a theoretically indeterminate quantity, and derives a result that is directly contrary to the well-established laws of hydraulics." It is worthy of note that, among all the hydraulicians who have read and discussed this paper, there is but one dissenting voice. On the other hand, the theory as presented has had the endorsement of such a man as I. P. Church, Assoc. Am. Soc. C. E., the author of a treatise on hydraulics—a man well known to hydraulic engineers throughout the world.

Prof. Gregory. For the benefit of those who require a rigorous treatment of the case presented by Mr. Maltby in Fig. 19, the following notes are added.

If, in Fig. 19, the entrance to the pipe from the vessel, K, had been made bell-shaped so that the cross-section would show rounded corners, there would be no appreciable loss of head at that point. The writer is well aware of the fact that a pipe in which water would flow without friction is an impossibility; but, if friction is taken account of, we will merely have the lines, $A\ B$ and $C\ E$, in Fig. 19, inclined downward, instead of as shown. This will in no way affect the reasoning given, as it is evident that the level at s and at E, B or H would be depressed by the amount of the friction head $\left(\frac{f L}{D} \frac{v^2}{2 g}\right)$; or, if the levels, E, B and H, be maintained in spite of friction losses, the pump would have to furnish an amount of energy which is increased by that represented by friction head, instead of the amount stated. The device shown in Fig. 19 was given to prove an important point, in the simplest possible way and without needless complications.

The writer might also have pointed out the fact that the velocity head, $\frac{v^2}{2 g}$, was all lost in every pump tested. This can be shown by an application of Borda's formula to Fig. 19. Within the pipe connecting K and L, the velocity of the water is v. If the vessel, L, is of considerable size, then, by Borda's formula, the loss due to the impact of water at a velocity, v, as it enters the vessel, L, is equal to $\frac{(v - v_1)^2}{2 g}$; where v_1 is the velocity of the water in L. But this velocity, v_1, is practically zero, and therefore the head lost equals $\frac{v^2}{2 g}$ and the water in the piezometer at n will, if friction in the pipe be neglected, stand at the height that is being maintained in the vessel, L; while, if friction is added, the level of the water in the piezometer at n will be raised by the amount of the friction head from n to the vessel, L.

The loss due to a sudden enlargement of section of a pipe in which water is flowing has been incorrectly stated in Appendix I of Mr. Venable's paper, "The Principles of Design of Velocity Pumps," presented before this Congress. The writer believes that Borda's formula is one of the "well-established laws of hydraulics," and possibly a more careful reading on the part of Mr. Venable will remove some of his doubts.

Mr. Venable also objects to the reading of pressure heads at the surface of a pipe in which water is flowing, and enters into a long dissertation in an attempt to establish what he considers a fact,

namely, that the pressure across a straight pipe in which water is flowing is not constant, and is greatest where the velocity is least, and least where the velocity is greatest. In short, he applies Bernouilli's theorem to various points in the cross-section of such a pipe. He evidently fails to grasp the significance of some experiments described by Mr. Maltby. However, if further proof is needed, it would seem that experimental proof should be the most convincing in the status of our knowledge of hydraulic laws. **Prof. Gregory.**

In a recent paper by the writer,* he gave a diagram showing four traverses of the discharge pipe of the U. S. Dredge *Epsilon,* in which the velocity curves and the static pressures were given. The static pressures were the actual pressures at the points of observation, and they were greater at the bottom than at the top of the pipe by the amount of the static pressure due to a head equal to the diameter of the pipe. Irregularities are no doubt due, in part, to the practical impossibility of keeping the steam pressure, and consequently the revolutions of the engines and pumps, absolutely constant. Each point plotted on this diagram is, in general, the average of ten readings, considerable time being required to complete a traverse, as much as an hour in some cases.

The following quotation is from that paper:

"It is seen from these results that the static pressure does not vary across the section of a straight pipe in which there are great differences of velocity parallel to the axis of the pipe, except as affected by gravity. This shows conclusively that the sum of static and velocity heads for various points in the same cross-section of a straight pipe, is not a constant quantity if we understand by velocity head, that due to the velocity parallel to the axis of the pipe. This ought not to destroy our belief in the Law of the Conservation of Energy. All the energy possessed by a particle of water at any point of the cross-section of a straight pipe is either energy or position, pressure or motion. Since the pressure energy is constant across a given section and the energy of motion parallel to the axis of the pipe varies, it follows that there must be energy of motion other than this. Unfortunately we have no way of measuring the velocity of the whirl of the particles of water at various points in the cross-section. If this could be done undoubtedly it would be found that the energy due to velocity of whirl is greatest at the walls and least at the center of the pipe, and that the energy possessed by a particle of fluid at one point in the cross-section is equal to that possessed by any other particle in the same section.

"It is impossible to convert this energy due to velocity of whirl into useful work; of course it is finally converted into heat."

So far as the writer is aware, this was the first proof, experimental or otherwise, of the fact that the pressure across a straight pipe in which water is flowing, is everywhere the same for all points,

* "The Pitot Tube," presented at the December, 1903, meeting of the American Society of Mechanical Engineers.

Prof. Gregory. except as influenced by the depth of the point under consideration. The conclusions deduced above are inevitable.

Messrs. Williams, Hubbell and Fenkell, in the closing discussion* of their able paper, entitled "Experiments at Detroit, Mich., on the Effect of Curvature upon the Flow of Water in Pipes," have fallen into the same error as Mr. Venable. The writer is willing to admit that the deduction was a very natural one, but, it cannot stand for a moment, in the light of experimental evidence to the contrary.

Experiments made by Mr. W. M. White show that if the impact end of a Pitot tube be made a surface of revolution with the opening at the center of that surface, the tube will show the correct head due to the velocity of the water at the point under investigation plus the static head at that point. The results given above show that the static pressure in a straight pipe is everywhere the same, when corrected for the height of the point under consideration. It therefore follows, that if the static head is obtained from a piezometer opening in the side of the pipe, at any convenient point, the difference of these two heads will give the head due to velocity.

Referring to the paper on "Water Measurements in Connection with a Test of a Centrifugal Pump at Jourdan Avenue Drainage Station, New Orleans, La.," by Mr. W. M. White,† and which has been criticised by Mr. Venable, it will be seen that the Pitot tube measurements used to calibrate what Mr. White calls a "velocity gauge" were entirely correct. The constant obtained for the tube used, by the comparison of static readings obtained from the side of the pipe in which water was flowing, as compared with the static head shown by the static openings of the tube, was substantially that obtained by hauling the tube through still water in a canal.

Further light was thrown on this point by certain tests, the final results of which are stated by Mr. Maltby. If, as has been contended by some, the constant for a Pitot tube, when used in a pipe under pressure, is different from that obtained by hauling the tube in an open channel, it follows that the results obtained from two tubes of exactly the same pattern will be different if used in a pipe at points having widely differing pressures. That this is not the case is shown conclusively by the curves in Fig. 5 of the writer's paper of December, 1903.

To test the accuracy of velocity measurements by two similar tubes and determine whether or not they were affected by static pressure, Tube 8 was placed in the discharge pipe of the second pontoon of the U. S. Dredge *Epsilon,* where the average static pressure was 19.78 ft. of water, and Tube 9 was placed in the ninth pontoon, 350 ft. from Tube 8, and where the average pressure was 4.12 ft. of

* *Transactions*, Am. Soc. C. E., Vol. XLVII, p. 335.

† *Journal of the Association of Engineering Societies*, October, 1900.

water. Traverses were made by taking observations simultaneously at different points across the pipe. The mean velocity determined by Tube 8, from 170 observations, was 22.321 ft. per sec., while that determined by Tube 9 was 22.351 ft. per sec., a difference of one-tenth of 1 per cent. Prof. Gregory.

The writer, therefore, maintains that the method used by Mr. White in calibrating his "velocity gauge" was a correct one, as the constant of the Pitot tube was accurately known, and also that the theory as stated by him was entirely in accordance with well-established hydraulic laws.

If the writer understands the objections raised by Mr. Venable to the methods used by Mr. White in the case referred to, they are, in part, based on the assumption that the pressure at the surface of a straight pipe is not the same as that at the center, or at the point of mean velocity. The fallacy of this assumption has already been pointed out.

Mr. Venable is greatly troubled by the pulsations in the discharge pipes of centrifugal pumps, which he refers to as "the chief source of difficulty in measuring the heads and velocities produced by such pumps, by the use of tubes." The writer does not believe that the comparatively slight pulsations caused by the passage of the blades of the runner of a centrifugal pump by the discharge opening will influence, to any marked degree, the mean readings of pressure on the discharge pipe. To establish such a proposition would require either a satisfactory mathematical theory or, preferably, some experimental data. Neither of these has been offered.

Mr. Venable would discredit the measurements made by Mr. Maltby on the loss of head due to friction in discharge pipes because the results do not agree with those computed by the formula given by Weisbach. Possibly Mr. Venable has not taken into consideration all the conditions of the problem. If friction head be expressed by the formula, $h = \frac{f L}{D} \frac{v^2}{2 g}$, the value of f, as advocated by Weisbach, was $f = 0.0144 + \frac{0.00172.}{\sqrt{v}}$

Mr. Maltby has given, on page ~~466~~ 457, some losses in head on the *Beta's* discharge pipe; the average value of f is almost exactly 0.014. The mean velocity was 20.1 ft. per sec.

Weisbach's formula, quoted above, gives $f = 0.0148$. The two results, therefore, differ by about 5%, which may easily be accounted for by the possible differences in the two pipes. It will be noticed that Mr. Maltby's results are lower than that given by Weisbach.

The results obtained on a portion of the straight discharge pipe of the *Beta* cannot be compared with the losses due to friction

Prof. Gregory. along the discharge pipes of the other dredges, for, in some of the latter, there was an unknown loss at the flexible connections, due to increase of section, and to the fact that the pontoons were not kept in perfect alignment; the difference in velocities in some cases would also account for slight differences.

The average value of f, as determined by the writer from the drop in pressure along discharge pipes and as stated in his report to the Commission, was as follows:

Name of Dredge.	Diameter of Discharge Pipe, in inches.	f
Gamma	34	0.0178
Delta	$34\frac{1}{2}$	0.0219
Zeta	32	0.0227
Iota	$32\frac{11}{16}$	0.0182
Kappa	$31\frac{7}{8}$	0.0165
Flad	3[illegible]	0.0222

The mean of these results gives almost exactly $f = 0.02$, while, by Weisbach's formula, $f = 0.0148$; the difference amounts to 26% of the value found.

The method used to measure the drop in pressure was the same in all cases. In one case, where joints and imperfect alignment were eliminated, it was found that the average result was 5% lower than that given by Weisbach, while, with flexible joints and imperfect alignment, the average result is considerably larger than the formula indicates. The writer was present at some of the tests, and knows that no special attention was paid to discharge pipe alignment, and that in some instances the pipe was far from being straight.

Shall it be concluded that one result was correct and the others wrong, or that both are wrong? An intimate knowledge of the methods used in these tests compels the writer to believe the results to be reliable in all cases, although the conditions are not fully stated in any case except that of the *Beta's* pipe. As a matter of fact, it is known that the value of f varies with the velocity and diameter of the pipe, and, as stated by Mansfield Merriman, M. Am. Soc. C. E., "the theory of the flow of water in pipes is not well understood." Very few experiments have been made on pipes of this size with the velocities used in dredging.

The writer agrees with Mr. Higgins that "some laborious research lies before those who will succeed in establishing a reliable formula for the work done by the runners of centrifugal pumps." There have been several contributions to the theory of these pumps in the last few years. Research along this line cannot be carried on by mathematical investigations alone; at each step theory must be

verified by experiment. The writer has tried to verify theories and make them agree with the results of these and other tests. While a pet theory will be borne out beautifully in a given case, the next case investigated will often upset preconceived theories. In the pumps tested by Mr. Maltby, a small number of blades was used in most cases; the path taken by the water is consequently difficult to locate and too little is known of the action of the water within the pumps to make a mathematical analysis of sufficient accuracy to be of much value. Special experimental investigations, covering a wide range, will be required before a mathematical analysis of real value can be made. Prof. Gregory.

F. B. Maltby, M. Am. Soc. C. E., Washington, D. C. (By letter.) —The writer wishes to acknowledge the uniformly kind expressions of appreciation of the paper presented by those who have seen fit to criticize it. Mr. Maltby.

Referring to the exceptions taken by Mr. Robinson, the writer believes that a part of them, at least, can be explained. The statement that an error was made in the original calculations of pump performance, in taking the head in feet of water, instead of in feet of material pumped, was poorly stated by the writer. As Mr. Robinson states the "head" here used is an expression of observed pressure and not as the actual height. The error in the original computations arises from the fact that the numerical value of the observed pressure in feet of water was used instead of reducing it to the equivalent in actual height of material pumped.

Mr. Robinson is, of course, correct in the statement that the head of material pumped is to the total head of water observed inversely as the weight per foot of material pumped is to the weight of water instead of directly as stated.

Mr. Robinson seems to infer that because the statement is made that the mercury in the gauges fluctuated through a space of, sometimes, 2 or 3 in., that the readings may be in error an inch or two. The writer can only reiterate the statement made that he believes that the mean of any one set of observations, all of which consist of ten or more readings, is corrected within 0.1 in. During the tests made in 1902, which extended over a period of about three months, and while adjusting and experimenting with apparatus, several hundred gauge readings were made which do not appear in the published results. A careful consideration of these readings gave the writer a great deal of confidence in their accuracy.

At one time the writer observed one of these gauges for about two hours, making series of ten observations each as rapidly as possible. Unfortunately the record of these observations is not now at hand as they were made for the sole purpose of demonstrating the accuracy of the readings. The means of single series agreed so

Mr. Maltby. closely that it was decided that they might be accepted without question.

In the paper written by J. A. Ockerson, M. Am. Soc. C. E., referred to above, the tests of the dredges given in Table 2 were presented with the original computed results.* In the discussion of this paper by Mr. Robinson, he objected to the results obtained for the *Epsilon*, which gave a net efficiency of 102 per cent. The writer had rather congratulated himself that by his recomputation he had been able to bring this efficiency below 100%, but still Mr. Robinson is apparently not satisfied.

Seriously, however, the writer does not of course advance any claim that the pump has any such efficiency; all the observations were presented for what they might be worth as he seriously objects to the practice of eliminating such observations as do not seem consistent with the preconceived idea of what they should be. The writer agrees with Mr. Robinson that these short-time barge tests contain elements of uncertainty, and for this reason he believes that only mean results for each dredge should be considered and not any single observations.

On the *Epsilon*, the efficiency referred to of 96.2% does not seem to be above the normal or mean efficiency to a greater extent than the lowest efficiency given, 68.5%, is below the normal, as the mean of all the observations in this series of tests on this dredge gives an efficiency of 83.7% as against 84.3%, omitting the first and last or highest and lowest observations. Mr. Robinson states that the results given by the *Zeta* are very different from those obtained on the *Epsilon*, the pumps being identical. The mean efficiency given for the *Zeta* is 80.3% as against those given above for the *Epsilon*, which does not seem to the writer a very great difference.

Concerning Mr. Robinson's criticism of Table 33, the writer refers to the text. On page 418, it is stated that water only was pumped; pages 418 to 434 are taken up in description of the apparatus and methods used in making these tests; the writer regrets that in these fifteen pages it is not made clear that a barge for measuring discharge was not used.

Mr. Venable attacks both the methods used and the accuracy of observations made in the tests of 1902, and evidently regards them as valueless, as he states that, in his opinion, the results are in error 25 to 30 per cent. The tests are certainly without value if such an error exists, and a further discussion of them would also be without value unless the accuracy of these methods and observations can be demonstrated. The method of measuring the power expended or supplied to and absorbed by the pump does not seem to be questioned; all calculations made to determine the amount of work done by the pumps are based on piezometric meas-

* *Transactions*, Am. Soc. C. E., Vol. XL, p. 215.

urements for determining head and the determination of velocity Mr. Maltby.
by Pitot tubes.

Mr. Venable does not question the accuracy of the latter measurements, in fact he appears to approve of them as he states, "upon the assumption that the velocity in the discharge pipes was measured correctly with the Pitot tubes, which is a fair assumption as the work appears to have been very carefully done." The error then all lies in the piezometer measurements.

Mr. Venable's criticism of these measurements does not seem quite consistent. He asserts first that a piezometer placed parallel to the flow at the outside boundary of the pipe does not measure the mean pressure throughout the pipe, and then even if it does the measurements made will indicate a greater pressure than actually exists. After demonstrating these two statements, he proceeds to use piezometric measurements observed on the *Zeta* as bearing out statements made by him in his paper on pumping machinery.

If these observations are in error 25 to 30% as he asserts, it would seem rather unwise to use them in demonstrating the truths of statements made in his own paper.

Let us, however, inspect these statements concerning piezometers. Referring to the first statement, that a piezometer placed at the outside boundary of the pipe does not measure the pressure at the center of the strain or the mean pressure of the stream. On page 428, the writer gives the results of certain measurements made with four piezometers placed in a 32-in. pipe, all in the same vertical plane, and the pressure side or static openings of a Pitot tube at the center of the pipe and in the same vertical plane as the piezometers. All the piezometers indicated the same pressure, and exactly the same pressure was indicated at the center of the pipe as nearly as could be determined by an ordinary mercury column and by three experienced observers. Either the pressure at the center of the strain was the same as at the boundary of the pipe or the errors of indication of pressure between piezometers and the pressure openings in the Pitot tubes happened to be exactly the same as the difference between the pressure at the outside of the strain and at its center, if such difference exists, which does not seem probable; furthermore, the writer made, during these tests, other measurements, not given in the paper, of the pressure at points located at intervals of 2 in. along the diameter of the pipe compared with piezometric measurements made at the same time and on the same section, and, in every case, the piezometric measurements were practically the same as the pressures measured at any point in the interior of the pipe at the same time.

These facts of observation, not theories or beliefs, would indicate an error in Mr. Venable's first statement concerning piezometers.

Regarding the second statement, that if a piezometer does meas-

Mr. Maltby. ure the pressure in the pipe, the gauge attached to it will indicate a higher pressure than actually exists owing to pulsations in the head created by the pump, the writer confesses that he is somewhat at a loss how to demonstrate the truth or falsity of such a belief. He can only say that Mr. Venable has not proven it to be true, and the writer certainly does not believe it is true to the extent of increasing the apparent head sufficiently to cause an error of 25 to 30% in results.

Mr. Venable lays great stress on the fact that in the tests of the *Zeta* with runners of different blades, approximately the same velocities of discharge were not accompanied by the same heads, therefore the measured heads must be wrong. It is undoubtedly true that, in a pipe under exactly the same conditions, similar velocities will be accompanied by similar heads. That similar velocities were not accompanied by the same heads in the tests of the *Zeta* indicates that the conditions of the suction and discharge pipes were not the same rather than that the heads were incorrectly measured.

It was intended that working conditions should be the same with each runner, that is, the pump casing, engines, and amount of discharge pipe should be the same in each instance. It was not the intention, however, at the time, to analyze the work done by the pumps, which consists of velocity into head, and to compare the component parts of velocity and head with each runner; rather, a comparison of total work done was desired. For this reason, no effort was made to keep conditions exactly the same. It may have occurred, and probably did, that the suction head was not lowered to the same elevation in each instance, and the discharge pipe may have had a greater or less deflection at the points. Any such variation would have caused a different head at the same velocities, though the velocity into the head compared with the indicated horse power may have been the same, and it was, within 3%, with all three runners on the *Zeta,* as stated.

The writer admits the possibility of a wide difference of opinion as to conclusions to be drawn from the tests made and does not enter into a discussion of such conclusions. His only desire is to demonstrate, if possible, the accuracy of results, that they may be of as much value as possible to others who may wish to study the performances of centrifugal pumps and draw their own conclusions.

Mr. Venable has taken occasion to attack at some length the arguments quoted from Professor Gregory, and, at the request of the writer, Professor Gregory has submitted a contribution to this discussion. The writer also wishes to acknowledge the assistance of Professor Gregory in preparing the mathematical discussion of the results of the tests.

Mr. Higgins asks why none of the gauge readings taken from piezometers located in the pump casings as shown in Figs. 24, 34, 36 and 37 agree with the delivery heads on the discharge pipe of the same pump. The piezometers on the pump casings were located along a horizontal line passing through the axis of the pump; the delivery head was taken at the flange of the discharge opening of the pump. The writer sees no reason why the same pressure should be indicated in different parts of the pump. **Mr. Maltby.**

The fact must not be lost sight of in the mathematical discussion of the performances of the pumps, that primarily a dredge is designed to handle material, and that its ability to do this in a fairly satisfactory manner is not dependent on a very close application of mathematical formulas in the design of the pump is very forcibly illustrated by Mr. Sturtevant, and it is shown on page 448 that the extreme range of efficiencies on six dredges and at various speeds varies only about 10 per cent.

The remarks of Mr. Sturtevant as to the cost of dredging per cubic yard on the Mississippi River are pertinent and directly to the point. The cost per yard cannot be given, not because there is any hesitancy in making public such information, but because it cannot be determined. The actual amount of material moved by these dredges cannot be measured. It would be impracticable to let by contract the work performed by these dredges except on the basis of a lump sum for maintaining a channel of a fixed depth. To maintain a channel 9 ft. in depth, as projected, has cost, during the last few years, about $250 000 per year. This amount includes all expenses of care and repair of plant and operating expenses. It is subject, however, to wide variations as the amount of dredging in one season may be double that of the preceding or succeeding years.

Answering Mr. Hall's questions, the cost of building a dredge of the self-propelling type and size of the *Kappa* would be, at present, about $175 000, complete with 500 ft. of pipe line. The size of the stones which a pump will handle occasionally is regulated by the screen bars, or about 6 by 8 in.

From the writer's experience with gravel, he does not believe that a suction dredge will operate economically in bars composed of a large proportion of gravel and only a small proportion of sand. In a bar of pure gravel, the material does not flow readily to the suction openings, and it is difficult to feed into the material. The pumps will handle the material readily if it can once be gotten into the suction pipes. The most serious objection to handling gravel arises from the enormous wear in the pumps and pipes. During the season just past, we have worn out the pump on one dredge which operated in gravel for less than two months. The entire runner and the linings of the pump casing will require renewing. The dis-

Mr. Maltby. charge pipe was worn entirely through. This pump would have operated in ordinary sand for at least ten months of actual dredging with only slight repairs.

Maj. Sanford. J. C. SANFORD, Philadelphia, Pa.* (By letter.)—Referring to the discussion of Mr. Robinson, regarding sea-going suction dredges, the writer would say that all these dredges were built under a fixed limit of cost and with a view to obtaining as large bin capacity as possible consistent with this limit and with reasonable speed and a thoroughly seaworthy hull, these being practically unalterable portions of the construction. On all the dredges, larger pumps can be placed at any time if found desirable, as each has a large surplus boiler capacity, the smaller pumps being then available for use on the smaller dredges. At some of the localities where these dredges work the distance to the point of dumping a load is very great (at New York Harbor, for instance, the time of pumping with the 20-in. pumps is only about one-third of the total working time), and it is essential that as large loads as possible be carried. Under the cost limit, if larger pumps and accessories had been provided, the hull and bins would have been correspondingly smaller, and it is doubtful if the saving in time of pumping would have compensated therefor, particularly in view of the fact, as stated above, that the size of pumps can afterwards be increased while the hull cannot.

One of the principal items of expense in operating these dredges is the cost and delay in repairing damages of the various parts of the pumping outfit. These dredges, being intended for work on bars in the open ocean, work usually in rough weather and often in storms of considerable force; moreover, these bars are often strewn with wreckage and heavy obstructions of all sorts. Under these conditions, the handling of the suction pipes requires the utmost skill, and, with the best handling, numerous accidents occur. With increase in size of pipes, the cost and time of repairing such damages increase, and, in certain localities, proper facilities for repairing very large suctions do not exist. All the larger sea-going suction dredges having been constructed at practically the same time, and none of them having been long in service, the question of the maximum size of pumps and accessories which can be used to advantage and economy on these bars has not yet been determined by experience; but it is possible that, for some of these localities, an increase in the size of pumps will hereafter be made. The dredge, *Chinook,* was constructed under peculiar conditions, described on pages 313 and 314 of the writer's paper, and as an experiment, it being seriously doubted if any dredge could work at the mouth of the Columbia River. It was regarded as of the utmost importance that this experiment should be tried at the earliest possible moment. The ar-

* Major, Corps of Engrs., U. S. A.

rangements for constructing her pumping machinery were, therefore, made by telegraph (the machinery ordered being practically a duplicate of that constructed for other dredges) for the purpose of saving time and because 20-in. pumps would be sufficiently large for the experiment and could be handled readily in the heavy seas usually found on this bar. A subsequent increase of pumping power, if the experiment proves successful, was had in mind at the time. Maj. Sanford.

Had there been no limit of cost on these dredges, triple-expansion engines would probably have been used, especially on dredges constructed for localities where fuel is quite expensive. Under the usual conditions of their work, however, compound engines have been found fairly economical.

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TRANSACTIONS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

VENTILATION OF TUNNELS.

Congress Paper No. 43.

By Charles S. Churchill, M. Am. Soc. C. E.,
Roanoke, Va., U. S. A.

Congress Paper No. 44.

By Francis Fox, M. Inst. C. E.,
London, England.

Discussion on the Subject by

Charles C. Wentworth, Roanoke, Va., U. S. A.
Thomas H. Johnson, Pittsburg, Pa., U. S. A.
P. F. Brendlinger, Philadelphia, Pa., U. S. A.
Charles S. Churchill, Roanoke, Va., U. S. A.

Note.—Figures and Tables in the text are numbered consecutively through the papers and discussion on each subject.

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VENTILATION OF TUNNELS.

By Charles S. Churchill, M. Am. Soc. C. E.

A careful study of the progress made in tunnel ventilation during the last ten years brings out clearly the following facts:

First.—Heavy increase in railroad traffic has made necessary the installation of ventilating systems in tunnels which, originally, were free from serious heat or accumulation of foul gases.

Second.—This same increase has shown the fallacy of "hit-or-miss" ventilation, and also of the system of "wire-drawing" mixed air and gases through a small shaft from a tunnel of large section. It has also proved that mechanical plants which were once measurably satisfactory are now wholly inadequate.

Third.—The public has become more critical, and what was once satisfactory is no longer accepted as good ventilation.

Fourth.—The accidental stoppage, at an intermediate point in a tunnel, of trains equipped with either steam or electrical power, has shown the importance of the frequent, complete and positive change of air in every part of a subway or tunnel.

Transportation companies have been seeking improvement in two ways:

The indirect way, of decreasing the cause of noxious gases, has led to abandoning the use of soft coal in some tunnels, and the

substitution of anthracite coal; next, coke; and finally, liquid fuel; and the last resort in this line is the substitution of electric for steam power.

The direct way has resulted in the installation of mechanical plants of increased power and efficiency, which furnish positive and well-controlled ventilation, such as demanded.

Tunnels in which the Ventilation is Improved by Indirect Means.

Arlberg Tunnel, on the Arlberg Railroad, between St. Anton and Langen, is 6.4 miles long, and has a sectional area of 442.6 sq. ft. Beginning at the eastern end, there is an ascending grade, in tunnel, of 0.2% for 2.6 miles; the remainder of the tunnel being on a descending grade of 1.5% to St. Anton. Of natural currents in this tunnel, those from the west predominate, but there is often a complete stoppage of currents for as long as 3 or 4 hr. during the period of reversion in the direction of the current.

As early as 1885, with moderate traffic, it was found to be impracticable to use coal for fuel in this tunnel, and coke was substituted. Beginning with 1890, several men were overcome with gases. The first remedy was to dry the coke and then use it while passing through the tunnel; the next was to keep trains 1 hr. apart; but serious accidents to employees still occurred. An experiment was then tried of conducting fresh air in a pipe laid along the masonry to a point far toward the center; but, this not being successful, petroleum fuel was tried in 1894. This proved so satisfactory that, in 1896, all locomotives were equipped for petroleum as a fuel, and its use in Arlberg Tunnel has since been continued.

The tunnels of the Metropolitan Railway, London, though partially ventilated, were the subject of serious complaints in 1897. The substance of the "Report of the Special Committee," named by the London Board of Trade, in 1897, to examine these tunnels, was as follows:

With a traffic of forty trains per hour as a maximum, natural ventilation is quite impracticable, and mechanical ventilation must be carried on on a large scale. The existing system of "wire-drawing" the air and gases from the large tunnel section of the

Metropolitan District Railway Tunnel, through two openings, about 8 ft. in diameter, and discharging them above the tops of the houses, was found quite inadequate. The existing traffic demanded a complete change of air in the tunnel every 2.5 min., or in the time required by a train to pass through the tunnel. A ventilating plant was suggested for each 0.5-mile section, to be located in the middle thereof; the stations to furnish inlets for fresh air each 0.5 mile, and the outlet shafts to have an area equal to the tunnel section, and be carried above the tops of the adjacent houses. The ventilating plant of each 0.5-mile section would be required to remove about 295 000 cu. ft. of air per min. This system was estimated to be very expensive.

This same Committee found the South London Electric Railway parallel tunnels, although equipped with frequent connecting cross-shafts between stations, to be musty, heavy and oppressive, and mechanical ventilation was recommended for these electric-power tunnels.

In conclusion, this Committee stated the most satisfactory plan to be the adoption of electric traction in all Metropolitan tunnels, which recommendation is being carried out.

The City and South London Railway line, at the outset, was constructed for the use of electric power. The iron tunnels or tubes being only 10 ft. 2 in., inside diameter, it was expected that the trains themselves would furnish ventilation, on the so-called plunger system; but, under moderate traffic, the air in these tubes was declared poor; and, early in 1902, through some slight derangement of traffic, a train was stopped between stations, and the air at once became more oppressive than the reporter had ever experienced from coal fumes in the Metropolitan Tunnels. It was found that the piston action of trains in these tunnels often drove the vitiated air backward and forward without furnishing ventilation. During 1902 a ventilating fan was installed at Bond Street Station, so as to change the air in the tubes periodically.

The Mersey Tunnel, at Liverpool, is 2 miles long, with an interior width of 26 ft., and 3% grades descending from both sides to pass under the Mersey River. The area of the section is about 425 sq. ft.; the cubical contents, between the river stations, are about 2 700 000 cu. ft.

This tunnel has often been referred to as having been originally constructed in 1886 with the most complete and scientific ventilating system. The stations on each side of the river are 1.2 miles apart, and underground. Above each of these stations is a ventilating plant consisting of two fans, 10 by 30 ft. in diameter, and two others, 12 by 40 ft. in diameter; the total capacity of the four fans being 500 000 cu. ft. of air per min. These two plants are connected with the tunnel by a parallel ventilating drift, 7 ft. 2 in. in diameter, connected to the tunnel at the central point, about 0.6 mile from each station, also at points about 0.25 mile from each station toward the portals. One of the four fans is attached to each section. Foul air is drawn out through these connections by the air drift, and the fresh air comes through the stations directly into the tunnel. This arrangement provides two fans having a total capacity of 260 000 cu. ft. per min. to the river section, 1.2 miles long, between stations. This plant gave satisfaction under a traffic of 300 trains per day, the spacing being one train each way, 5 min. apart. In recent years, however, under very heavy traffic, the air-shaft became coated with soot from 2 to 3 in. in depth, and the distance between the connections of this comparatively small air-way to the tunnel under the river has been found too great to give the ventilation now desired for the present traffic; consequently, it is reported that arrangements have been made for electrical power. Therefore, by avoiding smoke altogether, the present plant will certainly keep the air in the Mersey Tunnel pure.

Park Avenue Tunnel, New York City, on the New York Central and Hudson River Railroad, is 2 miles long, and is arranged for four tracks. About 0.5 mile is a single tunnel, of 50 ft. span, and the remainder is divided, by cross-walls, into one double-track and two single-track spans. About 1 mile of the former has openings, 20 by 150 ft., into the street on each street block, and 0.5 mile of the former has three ventilating shafts, 20 by 25 ft., on each street block. The single-span section, 0.5 mile long, has shafts, 4 ft. in diameter, up to the surface, spaced about 50 ft. apart. The sectional area of the tunnel of 50-ft. span is 1 062 sq. ft. The total sectional area of the 0.5 mile of divided tunnel ventilated by shafts aggregates about 870 sq. ft., and the total sectional area of divided

tunnel, 1 mile long, ventilated into the street by long openings, aggregates about 801 sq. ft.

After the accident in this tunnel, in 1891, compressed air was tried for a short time to improve ventilation, but was not a success. In 1901 the openings in the roof were declared by the press to be inadequate for the largely increased traffic, and the method was called "hit-or-miss" in its action because dependent upon natural air currents and those produced by trains either favorable or unfavorable to ventilation.

After the train accident of January 8th, 1902, in this tunnel, the improvement of its ventilation was again widely discussed. One plan advanced required five shafts, 2 000 ft. apart, alongside the tunnel, each shaft extending above the tops of the adjacent buildings, and having an area of 400 sq. ft. The plan required large inlets for fresh air midway between the shafts, and the foul air was to be drawn up each shaft by a fan at the foot having a capacity of 750 000 cu. ft. of air per min., giving a velocity of 1 000 ft. per min. in the tunnel. While it was acknowledged that there would be some reversals of currents between the shafts, it was claimed that the distances apart, of openings and shafts, were too short to conflict seriously with good ventilation.

The Railroad Commissioners of the State of New York, after making an extended study of the question, required that fresh soft coal be not used by engines passing through the tunnel, but that anthracite coal be used instead, and that no firing be done in the tunnel except on emergency; further, that there did not appear to be any feasible way of ventilating this tunnel, considering location and increasing volume of traffic; therefore, electric motors were recommended.

The increasing volume of traffic to be provided for seemed to be the determining factor, on the part of the New York Central Railway Company, which led to the construction work now in progress providing large additions to traffic facilities under electrical operation.

St. Clair Tunnel, on the Grand Trunk Railway, is 6 000 ft. long, and consists of an iron tube, 20 ft. inside diameter, arranged for one track. The descent under the river is 2 000 ft. long on each side, on a 2% grade, and the central section of 2 000 ft. is on a 1%

grade; the area of the section is about 300 sq. ft., and the cubic contents about 1 800 000 cu. ft. Two blowers were installed at each end of the tunnel, drawing air out of the tunnel through a pipe 2 ft. in diameter, the capacity of each blower being 10 000 cu. ft. of air per min.; so that, if effective, 45 min. would serve to remove a volume of air equal to the contents of the tunnel. This method of ventilation was reported in 1892 to be not entirely satisfactory; but the high ends of the tunnel aided ventilation, so that it cleared in reasonable time, but trouble from bad air occurred when trains broke in two in the tunnel. Since the latter part of 1892, engines at the heads of trains are run with tenders ahead so that the engineers will not be troubled with smoke and steam, and, further, anthracite coal is used for fuel.

Cascade Tunnel, on the Great Northern Railway, is 13 283 ft. long, on a 1.7% grade against east-bound traffic, and is a single-track tunnel, lined with concrete. No special ventilation is provided, and some trouble has been experienced from heat and gases, in the case of east-bound trains. At present these trains are pushed instead of being pulled through the tunnel. The pusher engine is provided with a special smoke-stack hood which directs the smoke backward instead of against the roof of the tunnel, this device having proved very helpful.

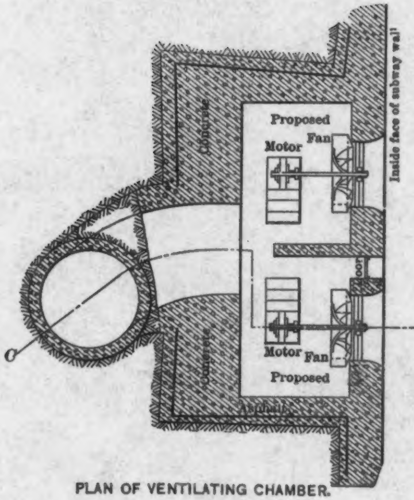
Tunnels Ventilated by Mechanical Plants.

Pracchia Tunnel, between Florence and Bologna, is 9 000 ft. long, and has a single track. It is built on a grade of 2.5 per cent. Freight trains require engines in front and rear, up this grade, and, until mechanical ventilation was established, the current was from the lower to the upper end, and the smoke of an up-train traveled with it.

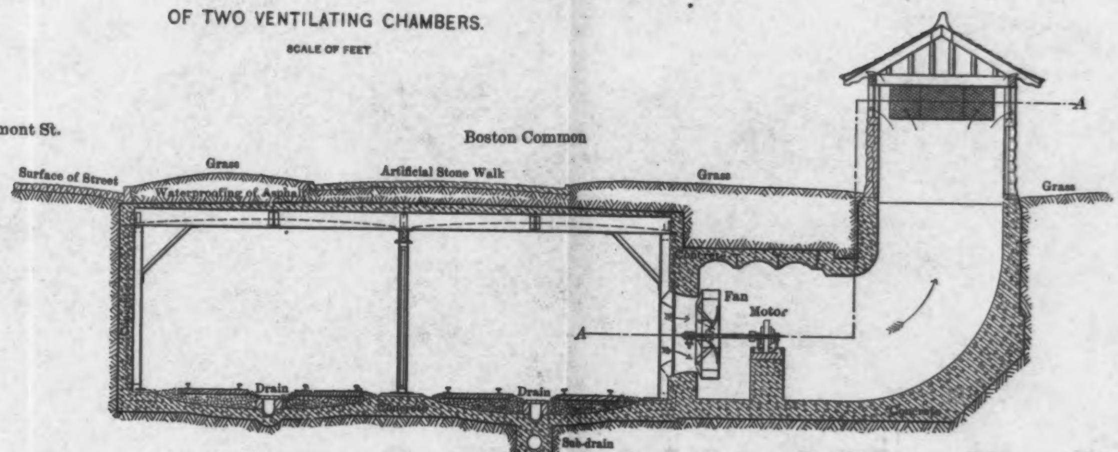
The Italian engineer, M. Saccardo, established a ventilating plant, at the upper end of this tunnel, which delivers 164 000 cu. ft. of air into the tunnel, and induces about 46 000 cu. ft. additional; total, 210 000 cu. ft. per min. at a water pressure of 1 in. This plant was described by Francis Fox, M. Inst. C. E., before The Institution of Civil Engineers, in 1898. Mr. Fox stated that it ventilates this tunnel successfully.

BOSTON TRANSIT COMMISSION.
PLANS AND SECTIONS
OF TWO VENTILATING CHAMBERS.

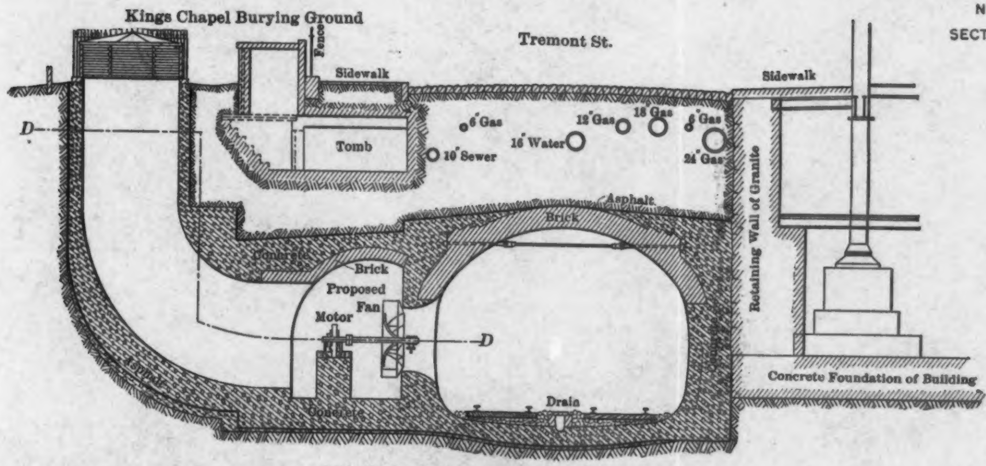
SCALE OF FEET



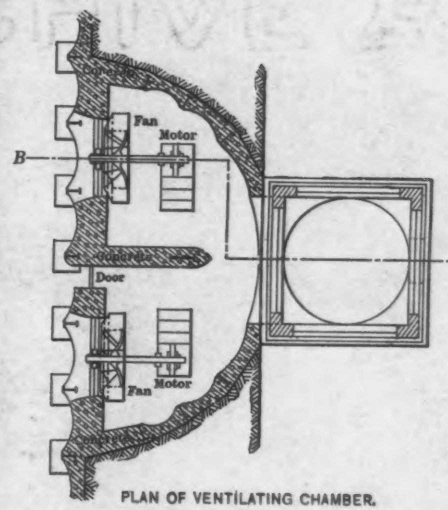
PLAN OF VENTILATING CHAMBER.
SECTION ON LINE D.D.



FOUR-TRACK SUBWAY AND VENTILATING CHAMBER.
NEAR WEST ST.
SECTION ON LINE B.B.



TWO-TRACK SUBWAY AND VENTILATING CHAMBER.
NORTH OF SCHOOL ST.
SECTION ON LINE C.C.



PLAN OF VENTILATING CHAMBER.
SECTION ON LINE A.A.

It consists of a fan discharging air into a chamber at the end of the tunnel, the discharge into the tunnel being through a space between the inner face of the tunnel and a lining inside of it occupying a portion of the tunnel section 23 ft. long, and made just large enough to pass a train. Reliance is placed, not only on the current from the fan, but also upon a current from the outside of the tunnel which is induced by the current directly from the fan.

St. Gothard Tunnel, on the St. Gothard Railway from Lucerne to Milan, is 9.3 miles long and 26 ft. wide. M. Saccardo, in 1899, installed at this tunnel a ventilating plant which is located at the north end; the direction of the current delivered is the same as the natural current. Two blowers are installed in a chamber which projects into the tunnel. This plant produces a current through the tunnel having a velocity of 552 ft. per min., which is found to be satisfactory. In 1897 the traffic through this tunnel amounted to sixty-one trains in 24 hr.

Giovi Tunnel, 6 miles long, north of Genoa, Italy, was also ventilated by M. Saccardo in 1902.

Simplon Tunnel, which is 12.4 miles long, is between Brieg and Iselle, on the Italian side of the Alps. It is straight, except for a short curve at each end, and is composed of two single-track tunnels spaced 55.76 ft. from center to center, each tunnel being 19 ft. wide and 19.3 ft. high. Only one of these tunnels, No. 1, has been built to the full section, the other being taken out to a width of about 6.5 ft. and a height of 10 ft., connected to Tunnel No. 1 by galleries every 656 ft., and used for construction needs.

For construction purposes first, and for operation purposes finally, permanent ventilating plants have been installed at the ends of this tunnel, each consisting of two 200-h. p. turbines, running 400 rev. per min., and driving two fans, 12.3 ft. in diameter. The fans are arranged somewhat differently at each end, but the arrangement at the Swiss end, as in Fig. 1, shows fully the ventilation system provided. At this end the fans are placed directly at the portal, one above the other (see plan), and the air passage is carried across the roof of the tunnel, thence directly, by a secondary passage, 11.5 ft. high, with an area of 36 sq. ft., to Tunnel No. 1 now operated. A similar air passage is provided at Tunnel No. 2. Doors in the main air passage provide for the delivery of air to

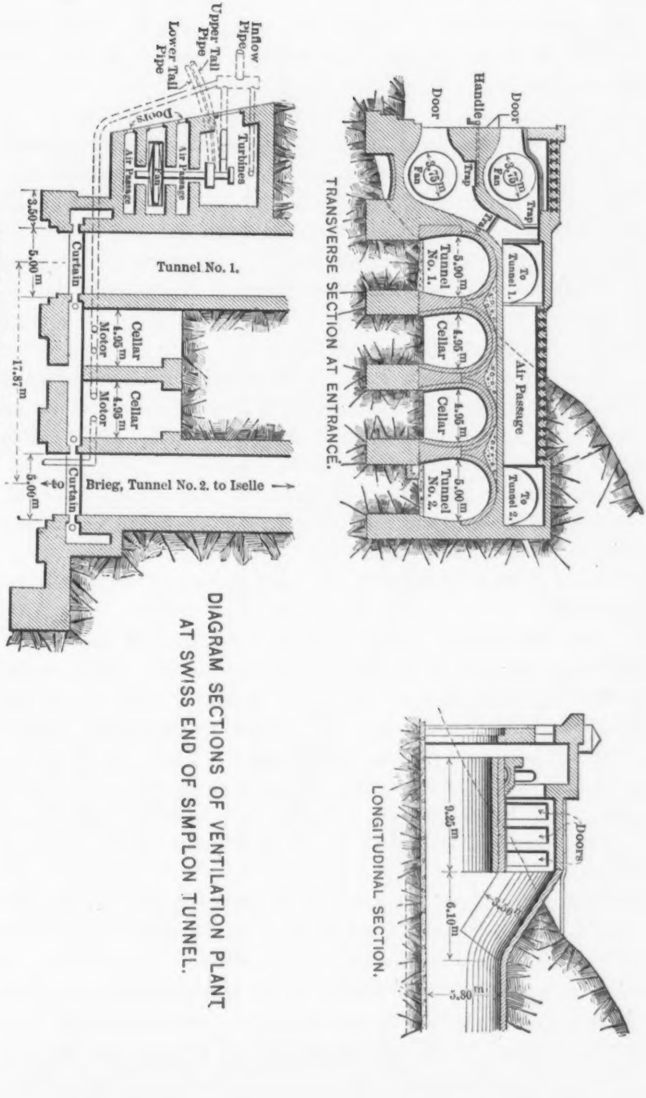
either tunnel. The plant at each end will furnish a maximum of 106 000 cu. ft. of air per min. at a pressure of 9.85 in. of water. Sail-cloth curtains, operated by electric motors, close the tunnel portals, and are required to insure ventilation under this system. The fans at the ends of this tunnel can be used either to draw gases out or force fresh air into the tunnel.

Hoosac Tunnel, on the Boston and Maine Railroad, is 4.7 miles long, and is straight, with a rising grade of 0.5% from each end to the center, where there is a shaft, 1 028 ft. high, the grades and shaft being favorable to natural ventilation. The tunnel has two tracks, and is from 24 to 26 ft. wide and 22.5 ft. high. The central shaft is elliptical in section, with diameters of 15 and 27 ft. The portals are protected by doors for use in winter as a preventive of ice formation in the tunnel. The shortest observed time of clearance of the tunnel by the shaft, in the winter, was about 20 min.; in summer, air currents descend through the shaft. The area of the section is 512 sq. ft., and the cubic contents are about 12 700 000 cu. ft.

In 1890, sixty-five trains per day through this tunnel was the maximum, and this number was regarded as being close to the limit for natural ventilation by shaft.

In 1899, a ventilating fan was installed on top of the central ventilating shaft, and arranged to draw smoke and gases from the tunnel through the shaft. The fan is operated by a 125-h. p. electric motor, the current being supplied from North Adams, 5 miles distant. When installed, this plant was not expected to ventilate the tunnel fully, and in 1900 the statement was made that, finally, a larger one would be advisable.

The Boston Subway Tunnel is about 1.8 miles long, the double-tracked sections having an area of 332 sq. ft., and the four-tracked sections, 707 sq. ft. The trains are operated by electric power. This tunnel is ventilated by exhaust fans set in chambers adjoining the tunnel and about midway between stations. These are placed vertically, and directly against the opening connecting the fan chamber with the tunnel. They take the air from the tunnel and discharge it upward, generally through grated openings in the street sidewalks, but, in two cases they discharge through low shafts, one of these being in Boston Common, the other in Kings Chapel



SECTIONAL PLAN OF TUNNELS.

TRANSVERSE SECTION AT ENTRANCE.

LONGITUDINAL SECTION.

DIAGRAM SECTIONS OF VENTILATION PLANT AT SWISS END OF SIMPLON TUNNEL.

FIG. 1.

Burying Ground. Fresh air enters at the stations and flows each way to the fans, the latter having been estimated originally to have sufficient capacity to move the air through the subway at a velocity of 60 ft. per min., and to change the air in the subway tunnel once in about 10 min.

A general idea of this ventilating system may be gained from the following description of two sections of the Subway Tunnel:

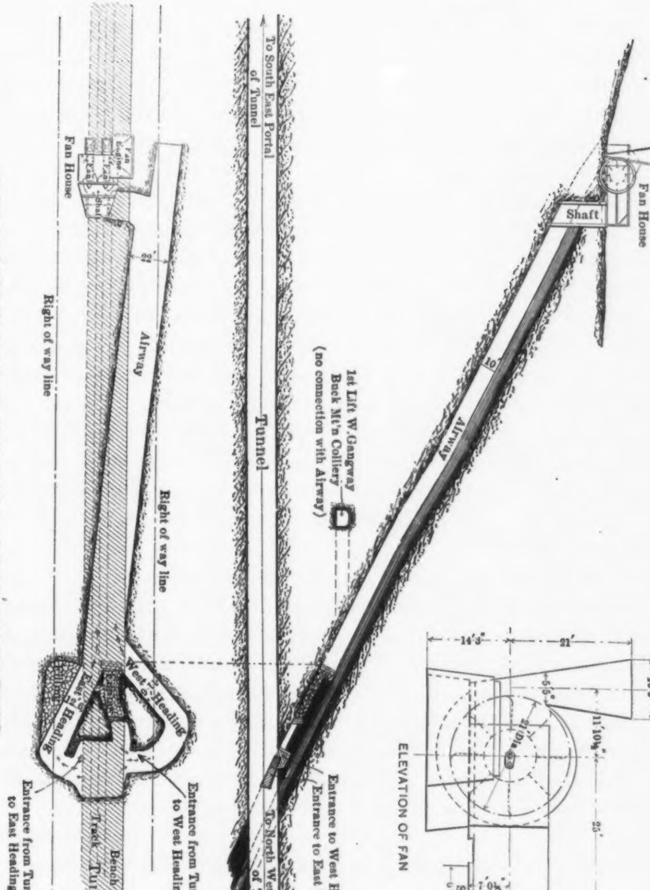
The section between Park Street Station and Boylston Street Station is four-tracked, its area is 707 sq. ft., and the distance between the centers of the stations is 1 250 ft. The cubical contents of this section of tunnel, therefore, are about 884 000 cu. ft. It is ventilated by two fans, each having a diameter of 8 ft., and a rated speed of about 225 rev. per min., the fans being located about midway between the stations.

The section between Park Street Station and Scollay Square Station is two-tracked, its area is 332 sq. ft., and the distance between the centers of the stations is 1 450 ft. The cubical contents of this section of tunnel, therefore, are about 481 000 cu. ft. It is ventilated by two fans, each having a diameter of 7 ft. and a rated speed of about 225 rev. per min., the fans being located about midway between the stations.

Plate XXXVIII shows clearly the method of installation and operation.

East Mahanoy Tunnel is on the Philadelphia and Reading Railroad, 2.2 miles east of Mahanoy City. It is 3 406 ft. long, straight, and on a grade of 0.7% rising to the north. While built for a single track, the upper half of the section is enlarged partly toward a second track, the sectional area being 336 sq. ft. and the cubical contents about 1 145 000 cu. ft. Traffic through this tunnel is quite heavy, and, before a ventilation plant was installed, the air in the tunnel was often so foul that it became unsafe for crews of slow trains.

The plan adopted for ventilating this tunnel took advantage of an old slope, excavated in the Buck Mountain Coal Vein, by using this opening, which is directly over the tunnel, as an air-way. This air-way enters the tunnel 850 ft. from the north portal and 2 556 ft. from the south portal. It has an average area of 150 sq. ft., and its total length is 385 ft. At the top of this air-way there is a



AIRWAY IN BUCK MOUNTAIN VEIN TO VENTILATE EAST MAHANOY TUNNEL.

FIG. 2.

double fan attached to one shaft, the diameter of the fan-wheels being 21 ft. The normal speed of the fans is 100 rev. per min., and the boiler power is rated at 120 h. p. The area of the tunnel has been reduced, north of the air-way, to compensate for the difference in length from the air-way entrance to each portal, the distance to the north portal being only about one-third of that to the south portal. This reduction to a tunnel section of 198 sq. ft. (being just large enough to pass trains safely), is made at a point 155 ft. from the north portal.

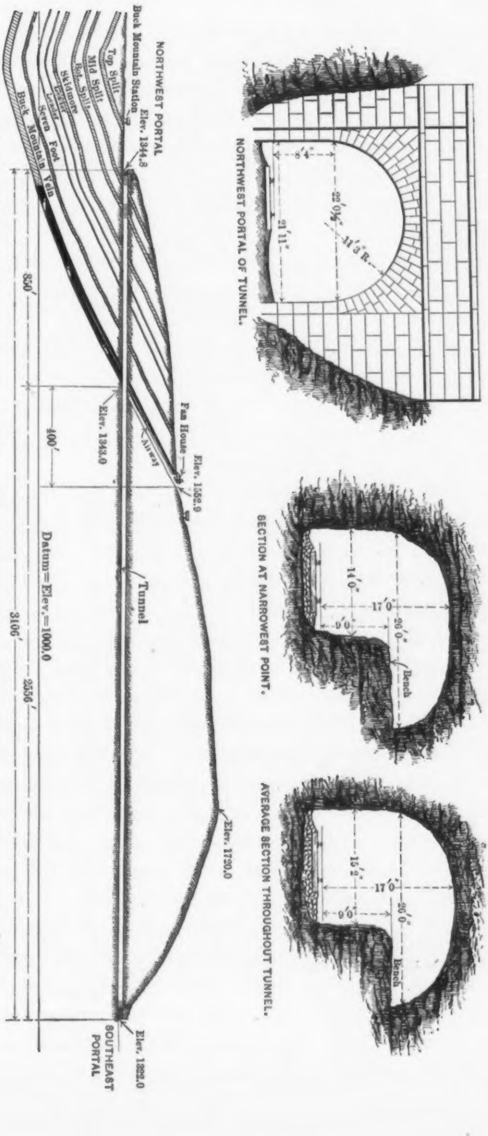
After completion, in 1900, the fans, at normal speed, were found to remove 251 000 cu. ft. of air per min.; so that the contents of the tunnel can be displaced in about 5 min. if all the air should pass up the air-way. During April, 1903, a test was made of the time required to clear the tunnel after the passage of heavy trains. The average time after each of eleven north-bound trains in good clear weather was 12 min., and the average after each of twelve south-bound trains was 10½ min. It is found that it is much more difficult to clear this tunnel on a wet, foggy day, and the time also varies with the condition of the wind and the temperature; but the foregoing is stated to be a fair average in ordinarily good weather.

Figs. 2 and 3 show the local conditions and the detailed arrangement of this plant.

The Baltimore Tunnel, on the Philadelphia, Baltimore and Washington Railroad, is located under Wilson Street, Baltimore, extending from Pennsylvania Avenue to near North Avenue, and has a length of 3 700 ft. North of this the roadbed was in excavation for a distance of 200 ft., followed by another tunnel, 945 ft. long. The portion under Wilson Street is straight; the remainder is on a curve. The grade is 1.35%, rising toward the south. The maximum width of the section is 27 ft., with two tracks; the height is 22 ft., and the area of the tunnel section is 444 sq. ft.

In 1892 a plant was installed at the corner of Madison Street, 1 460 ft. from the south end of the tunnel, to ventilate the southern tunnel, 3 700 ft. long, the plant consisting of one fan, 15 ft. in diameter, discharging through an air-way, having an area of 117 sq. ft., into a stack, 100 ft. high, the sectional area of which is 182 sq. ft. This fan is operated at about 150 rev. per min.

This plant alone has not been entirely satisfactory in its



SECTIONS OF BROAD MOUNTAIN AND OF EAST MAHANOY TUNNEL, SHOWING BUCK MOUNTAIN VEIN WORKINGS IN ANTHRACITE COAL.

Compiled from drawings of John H. Pollard, Assistant Engineer, P. & R. C. & I. Co., by E.F. Smith, C.E., Nov. 17, 1900.

FIG. 3.

operation. Trouble was experienced from soot being deposited in the stack, which, after it had reached a certain thickness, blew out and constituted a public nuisance in this residential district. It was further desirable to close in the open cut and remove all smoke from both tunnels through a stack. The closing in of this open cut connecting the two tunnels makes a continuous tunnel 4 845 ft. long, with a cross-section of 444 sq. ft. It is expected that the new ventilating plant will be completed and put into operation early in May, 1904.

Fig. 4 shows the location of the fans and stack on North Avenue, 765 ft. from the north end, and also the arrangement of the plant.

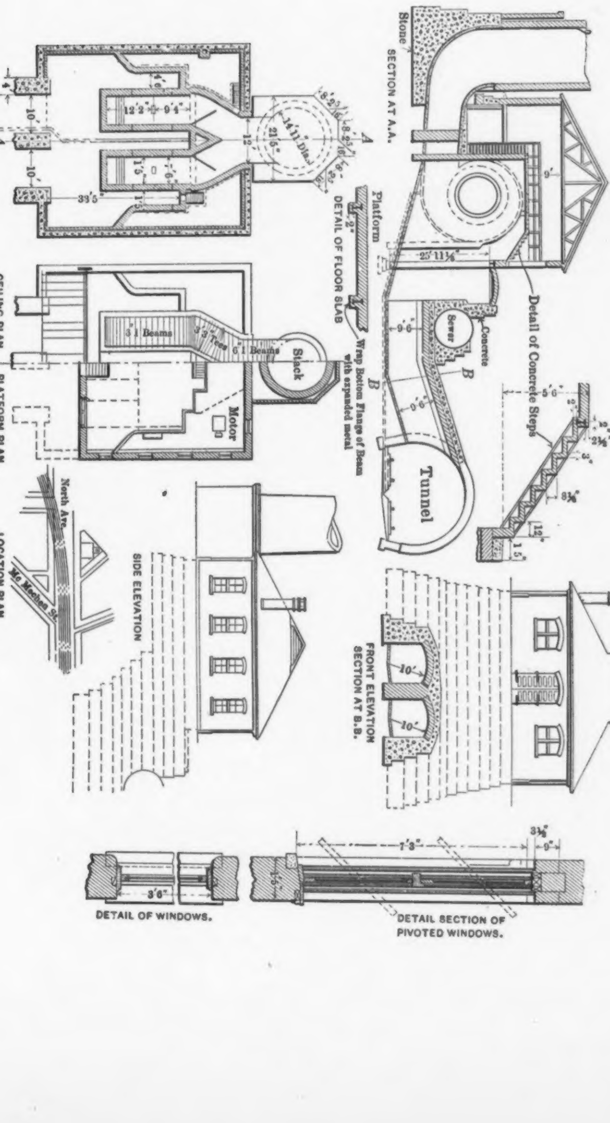
The air-way from the tunnel to the fans has a total sectional area of about 198 sq. ft. The fan-house contains two fans, each 7.5 by 15 ft. in diameter, operated by electric motors at a normal speed of 78 rev. per min. Each fan is capable of discharging 113 000 cu. ft. of air per min., or a total of 226 000 cu. ft. per min. into the stack.

The total cubical contents of this tunnel are 2 151 000 cu. ft.

The North Avenue stack is 150 ft. high, with a maximum inside section of 177 sq. ft. at the bottom, and a minimum inside section of 113 sq. ft. at the top. A 2-in. galvanized pipe extends from the base to near the top of the stack, and 18 in. from the top, it is connected with a ring of 2-in. pipe which encircles the inside of the stack. In this ring ⅛-in. holes are drilled, spaced at about 6 in. from center to center. They stand at an angle of about 45° from the horizontal, with a discharge downward and toward the wall of the stack. This device is expected to wash the soot from the inside of the chimney to the bottom, and the washing is done two or three times a day, depending upon the quantity which accumulates.

The electric current to operate this plant is furnished from a power-house at the north portal of the tunnel, and the feeders are of lead-covered cable running through the tunnel.

Big Bend Tunnel is on the Chesapeake and Ohio Railway, near Hinton, West Virginia. It is a straight, single-track tunnel, and is 6 500 ft. long. It has a width of 15 ft. 3 in., a height of 17 ft. 9 in., and is lined with brick. Its sectional area is 250 sq. ft., the cubical contents of the whole tunnel being 1 625 000 cu. ft. There is an ascending grade of 0.4% from the west end of the tunnel for



BALTIMORE TUNNEL VENTILATION. POWER HOUSE.

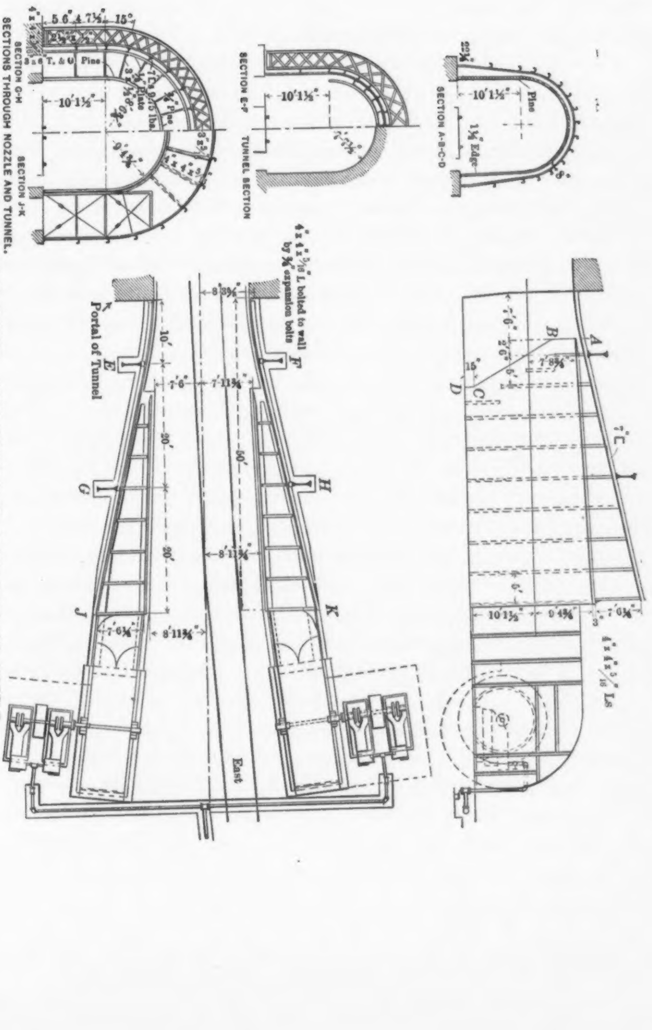
FIG. 4.

two-thirds of its length, followed by a descending grade of 0.08% to the east end.

Until mechanical ventilation was installed, in the latter part of 1902, reliance for the clearance of smoke and gases was placed upon two shafts located about one-third way from each end, and extending from the tunnel to the top of the mountain. Natural currents were inadequate for clearing, however, and, under an average daily traffic of forty-five trains, the gases were very bad and employees were affected seriously by them.

Fig. 5 shows the general arrangement of the ventilating plant, which is at the eastern or upper end of the tunnel, the type of the plant being the same as that installed previously at Elkhorn Tunnel, on the Norfolk and Western Railway. It consists of a nozzle, 50 ft. long, attached to the east portal, the minimum interior cross-section of which is the same as that of the tunnel. This nozzle is composed of latticed steel ribs to which are riveted longitudinal channels, which together form the framework, which is covered by ⅛-in. steel plates. The inner surface of the nozzle is formed of 3 by 6-in. tongued and grooved, dressed pine sheeting, put together tightly, attached securely to the outer framework, and covered, finally, with an asbestos paint. The inner end of the nozzle is secured to the tunnel portal, and to the outer end are attached the outlets of the fans, one on each side of the track. These fans are 7 ft. wide and 14 ft. in diameter, each coupled by two 12 by 14-in., center-crank, steam engines, fed from boilers located a short distance east of the fans. At the rated speed of 144 rev. per min., these two fans deliver into and through the tunnel, by the nozzle, a total of 300 000 cu. ft. of fresh air per min., the measured velocity of the moving current in the tunnel being 1 200 ft. per min. As operated at present, these fans do not run with speed except when trains come to the tunnel at either end, when the average velocity does not generally exceed 120 rev., at which rate the two fans deliver through the tunnel a total of 250 000 cu. ft. of air per min. Under the ordinary plan of operation, the tunnel is cleared in from 7 to 9 min. after the passage of a full-tonnage, east-bound train, the time being dependent on the speed of the fans. A shorter time is required to clear the tunnel after a west-bound train.

The fans and engines are constructed to run at a higher velocity than 144 rev. per min., so as to deliver, if required, as much as



VENTILATING BIG BEND TUNNEL. ARRANGEMENT OF BLAST FANS AND NOZZLE.

Fig. 5.

400 000 cu. ft. of fresh air per min. through the tunnel; but, up to this date, only a portion of the boiler plant has been installed.

The original shafts in this tunnel have been closed, and the smoke and gases, as mixed with the fresh air from the plant, are forced out of the west portal of the tunnel by the large volume of pure air passing through it from the east end.

The result of the installation of this plant has been a prompt clearing of the tunnel after the passage of each train, and a clear cool atmosphere on the arrival of every following train, and, as a consequence, the tonnage loading of east-bound trains has been increased from 1 700 tons, which was the rating before the installation of this plant, to the present rating of 1 928 tons.

Elkhorn Tunnel, on the Norfolk and Western Railway, is at Coaldale, West Virginia, on the divide between the waters of New River and of Big Sandy River. This divide, in Flat Top Mountain, is crossed, at an elevation of 2 386 ft., by means of Elkhorn Tunnel, which is 3 000 ft. long, and has a single track, between two sections of double-track railroad. The straight portion of this tunnel is 2 167 ft. long, and 833 ft. at the eastern end is on a 2° curve. The approach from the west is on an up-grade of 2.0%, reducing at the west portal to 1.4%, which rate of grade extends through the tunnel to the summit, located a few hundred feet east of the east portal. The tunnel is 14 ft. wide and 19 ft. high, having a cross-section of 235 sq. ft. The cubical contents, therefore, are 705 000 cu. ft.

A considerable percentage of "Pocahontas" coal, mined from the west slope of Flat Top Mountain, and destined for shipment east, was hauled up the adverse grade, and through this tunnel, either by two heavy engines each weighing 133 tons, with tender, or by three engines of ordinary weight to each train of about 1 200 tons. If two engines were used, one was generally placed at the head of the train and one in the rear. In case three engines were used, one was placed at the head of the train, one near its center, and one in the rear, which inconvenient arrangement, as a result of good ventilation, has since been changed. The records at the time of the construction of the ventilation plant show the number of two-engine, east-bound trains, to be about eighteen in 24 hr., and of three-engine, east-bound trains, about thirty-nine. The total number of all movements through the tunnel, both east and west, being nearly one hundred per

24 hr. East-bound trains, several in number, frequently stand to the west of the tunnel, and follow each other through the tunnel as quickly as they get signal that the train ahead has passed out of the block, which ends a few hundred feet east of the east portal. Freight engineers naturally hurried through the tunnel as quickly as possible; the time of a fully-loaded, east-bound, freight train being about 5 min.

On account of the heavy grade through this tunnel, and the number of engines used in a train, the quantity of smoke and gas emitted from one train is very great, and the conditions to which train crews were subjected before the installation of the ventilating plant, were bad. Notes taken prior to ventilation showed that in summer from 17 to 55 min. were required for the tunnel to clear after the passage of a train. The shortest time of clearance noted was in winter, when it averaged about 20 min., though it was frequently longer. Each train crew, therefore, generally had to contend with not only the smoke of their own train, but also that of one or more previous trains. The temperature inside the tunnel became about 30° higher than the outside temperature, on the passage of a train; that is, with the outside temperature at from 70 to 75°, that found 1 000 ft. from the east portal was 103°, and this became still higher as the outside temperature increased.

During the four years immediately prior to the installation of a ventilating plant, twenty-six men were asphyxiated in the tunnel, only one of whom, however, lost his life.

Early in 1[illegible]0 the Norfolk and Western Railway Company decided to ventilate this tunnel, and, later, it was concluded that the best plan to secure the desired positive results was to ventilate it from one end by forcing fresh air through the whole tunnel, but by such construction as not to decrease the cross-section of the tunnel at any point and also provide for future increase of traffic, as well as give more complete protection to trainmen than had ever been attempted before.

The essential features of the plant devised are:

First.—Fans of proper dimensions and speed installed at one end of the tunnel for driving fresh air into it at the pressure determined upon; and

Second.—A funnel-shaped nozzle, constructed so as to preserve

the cross-section of the tunnel, and at the same time provide a reduced area of outlet through which a blast of clear air can be delivered at a velocity necessary to insure its passage through the entire length of the tunnel, carrying smoke and gases before it.

It was decided to enlarge the tunnel portal at the west end, and make the back wall of the nozzle of masonry. The plan was adopted: First, because, there being a curve near the west end, a lengthening of the tunnel a few feet would cause several complications; second, because there is nothing more permanent than good masonry; and, third, because the calculations having been made in advance, the plant was not regarded as experimental.

The plant was located at the west end: First, because east-bound freight trains have two or three engines at different points in the train, as heretofore described, and, therefore, it was desirable, not only to clear the tunnel of smoke quickly, but also to force the smoke away from the engine cabs and protect the engineer and fireman as far as possible from the smoke and heat of their own engine. Therefore, a blast was planned, sufficient in amount to drive the smoke ahead of each east-bound engine, instead of trailing into its cab, as happens in all tunnels.

Fig. 6 shows the general lay-out adopted. Fig. 7 is a plan of the nozzle with details of its outlet. Fig. 9 is a cross-section of the tunnel; a half elevation of the outer end of the nozzle and portal; and a half cross-section of the nozzle near its outlet. Fig. 8 gives details of the nozzle construction, including all iron ribs. Fig. 1, Plate XXXIX, shows the nozzle in process of construction inside of the enlarged portal. The partially erected fans appear in the foreground. Fig. 2, Plate XXXIX, shows the completed plant, consisting of two fans, 14 ft. in diameter, each operated by an engine of 75 nominal h. p. The boiler-house is seen on the north of the track, west of the fans, and the outer end of the air chamber, or nozzle, built in the enlarged portal, appears in the background. The fans are controlled from a valve in the boiler-house, so that the whole plant is subject to the operator at one point. At 140 rev. per min., these two fans deliver air through the nozzle at the rate of 200 000 cu. ft. per min. per fan, or a total of 400 000 cu. ft. with a speed through the tunnel of 1 700 ft. per min.

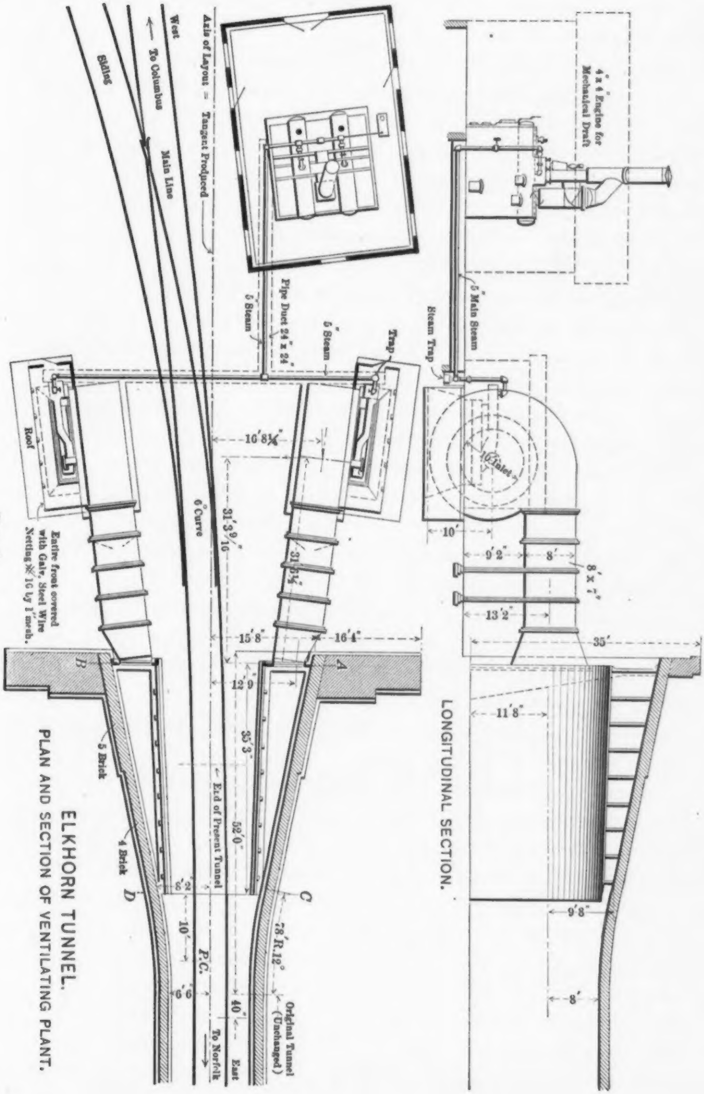


FIG. 6.

ELKHORN TUNNEL.
PLAN AND SECTION OF VENTILATING PLANT.

The average cost of operation per month is: labor, $176; fuel, etc., $94; total, $270.

Two, of a series of tests made in 1901, are as follows:

A three-engine, east-bound train, loaded with coal, passed through the tunnel in 6 min., while the fans were running at 142 rev. per min. The observer on the first engine rode on the tank, and the engineer had the windows of the cab open. He reported the tunnel entirely clear, two-thirds of the way through, and there was no objectionable smoke anywhere. The engine-men reported the tunnel "O. K." An observer at the east portal reported that the smoke of the train came out 2 min. ahead of the first engine. The observer on the second engine rode in the cab, with all the windows open. He could see the smoke of his engine seven car lengths ahead, there was no smoke behind the tank; the tunnel was clear at the engine, and cool. The observer on the rear engine rode in the cab, with the windows open; he found the tunnel practically clear and no smoke behind, showing that fresh air was with his engine throughout. A small quantity of steam adhered to the brick roof near the east portal, but this passed out in about 1 min. after the engine. The reports of the engine-men agreed with these as to the tunnel being clear and cool.

A two-engine train, east-bound, passed through the tunnel in about 5.5 min., while the fans were making 140 rev. per min. All the cab windows of the engines were open. The engine-men reported the tunnel clear and cool.

The following is the actual method of operation to meet present requirements at Elkhorn Tunnel:

Except when trains are approaching from the west, the fans are kept moving slowly at not more than 30 rev. per min. This keeps the tunnel both clear and cool; and this same speed is used in case of all west-bound trains, which, on account of the down grade, emit comparatively light smoke. On the approach of an east-bound freight train, the fans are run at about 140 rev. per min., which is maintained until the operator of the ventilating plant receives the signal, by the track circuit, that the train has cleared the tunnel. The operator then shuts off steam enough to reduce the speed to not more than 30 rev. per min. In the case of three-engine trains, where, before ventilation, it was necessary for the safety of the crew

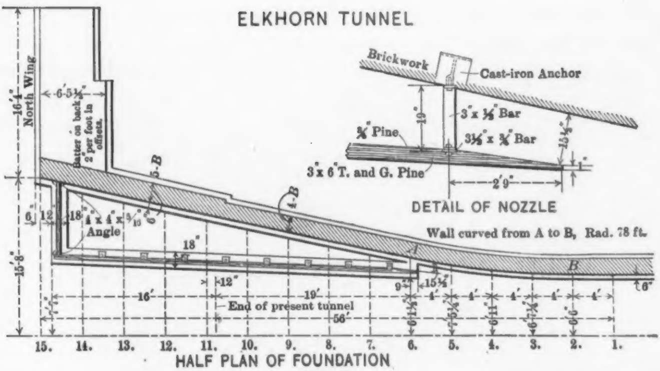

ELKHORN TUNNEL
Brickwork
Cast-iron Anchor
3" x ½" Bar
¾" Pine
3½" x ¾" Bar
3" x 6" T. and G. Pine
2' 9"
DETAIL OF NOZZLE
Wall curved from A to B, Rad. 78 ft.
North Wing
Batter on back 2" per foot in offsets.
Angle
End of present tunnel
HALF PLAN OF FOUNDATION

FIG. 7.

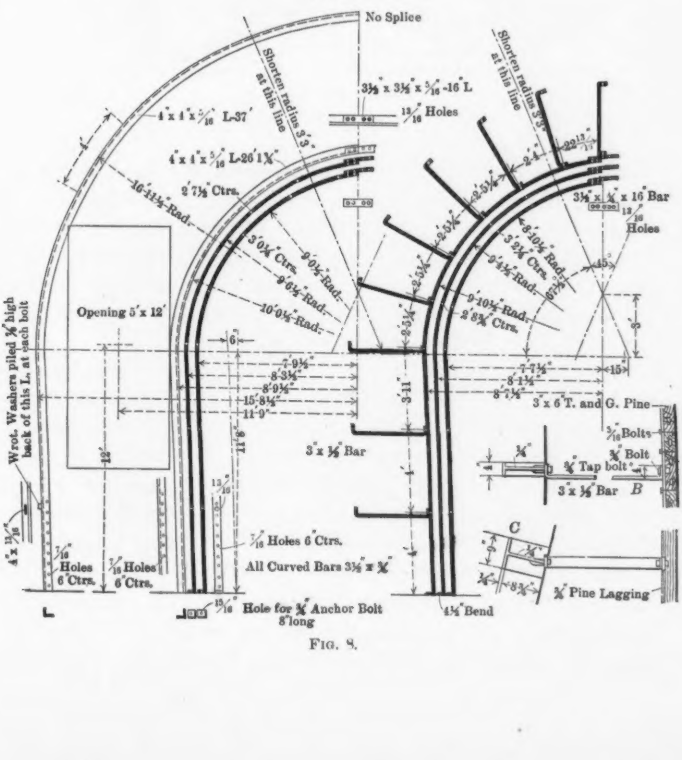
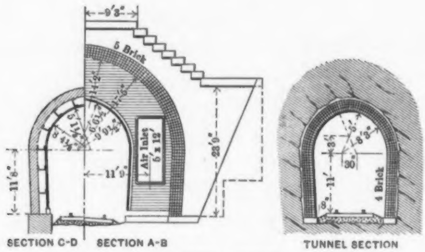

No Splice
Shorten radius 3' 3" at this line
13/16 Holes
Opening 5' x 12'
Wrot. Washers piled ⅜" high back of this L at each bolt
3" x ½" Bar
7/16 Holes 6" Ctrs.
All Curved Bars 3½" x ¾"
Hole for ¾" Anchor Bolt 8" long
4½" Bend
3" x 6" T. and G. Pine
¾" Pine Lagging

FIG. 8.

to place one engine near the center of the train, the ventilating plant has admitted the placing of the third engine, with the second, at the rear of the train, thereby saving much loss of time and inconvenience in cutting out, at the summit east of the tunnel, the engine formerly placed near the middle. In the case of east-bound passenger trains, the clear tunnel, which is always furnished ahead of trains, is sufficient, but the fans are generally operated.



SECTION C-D SECTION A-B TUNNEL SECTION

ELKHORN TUNNEL

FIG. 9.

Since the installation of this plant, pneumatic interlocking has been placed at Coaldale, controlling all switches and signals for a considerable distance beyond both ends of the tunnel, power being furnished from the boilers at the ventilating plant; and the boiler capacity has been increased to a total of 300 nominal h. p.; further, a brick chimney (not shown on the plans) has been substituted for the original mechanical draft of the boilers.

The results secured by this plant may be summarized briefly as follows: The tunnel is free from smoke, independent of the number of engines used, or the frequency of trains. The temperature of the tunnel is always good. The tonnage loading of trains has been increased on account of the improved condition of the rails. Trackmen now prefer to work in the tunnel rather than outside, thus reversing the former condition. No difficulty ever arises in case of a train breaking in two in the tunnel; for, even if the fans are running at slow speed, fresh air quickly surrounds the standing train. It is immaterial whether or not the windows of passenger coaches are closed in passing through the tunnel. It

FIG. 1.—ELKHORN TUNNEL. INSTALLATION OF VENTILATION PLANT.

FIG. 2.—ELKHORN TUNNEL. VENTILATION PLANT COMPLETED.

seldom happens that light smoke is seen coming out of the east portal longer than 1 min. after the clearance of a train; and, in good weather, it is generally clear when the train leaves it.

The illustrations furnished, in the descriptions of the various ventilating plants, have been selected, as far as practicable to obtain them, so as to show the relative efficiency of the several installations through the results secured.

Inasmuch as complete ventilation of a tunnel requires that all the air therein be displaced by fresh air in a given period of time; the length of the tunnel, the cross-section, the cubical contents, the volume of air moved per minute, and the observed time needed to secure a clear tunnel after a train, are all figures which show readily just what is accomplished, and the relative completeness of the results.

The term "satisfactory ventilation" is variable in its meaning, as a comparison of these figures will show. While it includes complete ventilation, it is more often applied to less complete degrees of dilution of the gases.

The data will also make apparent cases where "wire-drawing" of air and gases is taking place, through the use of air-ways which are too small, as compared with the tunnel section, also where the movement of fresh air is indirect.

A consideration of the cross-section, together with the results cited, shows the error of dependence upon train movement to help ventilation materially. On the contrary, it interferes with ventilation more frequently in single-track tunnels; and this fact, together with the frictional resistance and the small air space around a train, makes the ventilation of a double-track tunnel less difficult than the ventilation of two single-track tunnels of the same length.

It will be noted, further, that tunnels operated by electric power require ventilation as well as those operated by steam power. The difference is in amount only; the principles governing its application are the same.

It is sometimes stated that, in the case of railroad tunnels built for two tracks, dilution of smoke and gases, rather than the clearance of the tunnel in a given period of time, should be the basis for estimating plants for mechanical ventilation. Practically, the two methods will give like results if the standard is equally high.

Assume a railroad tunnel, 1 mile long, double-tracked, having a section of 444 sq. ft., and located on a ruling grade. The cubical contents amount to about 2 345 000 cu. ft.

A freight engine, weighing about 185 000 lb., without tender, will, when fully loaded, travel not more than 12 miles per hr. under such conditions, and the speed may be as low as 8 miles per hr. Taking 12 miles as a basis, and the spacing of trains on each track as 10 min. apart, each train will consume 5 min. in the tunnel. Such an engine will emit from its stack at least 20 000 cu. ft. of smoke and gases per min. in addition to steam. All this is impure, hot and unfit for breathing, containing about 2 500 cu. ft. of carbonic gases; and so the whole of these emissions from the smoke stack should not constitute more than 2% of the air passed through by the train. The emissions in 5 min. will amount to 100 000 cu. ft., and should be balanced by 4 900 000 cu. ft. of good air. As the tunnel contains 2 345 000 cu. ft., there remains to be supplied, every 5 min., 2 555 000 cu. ft. of fresh air by a strong current, or at the rate of 511 000 cu. ft. per min.

Under the other method, it is stated that the contents of a railroad tunnel, in cases of close train spacing, should be entirely renewed in the time required for the passage of a train. In the foregoing example, this would mean displacing the total cubic contents of the tunnel, or 2 345 000 cu. ft. in 5 min., which is at the rate of 469 000 cu. ft. per min.

From personal observation, the writer ventures the opinion that any single-track railroad tunnel, more than 2 500 ft. in length, will require ventilation before the transportation capacity of the single track through the tunnel is reached. About sixty movements per day through such a tunnel, unless local conditions are especially favorable, seems to be the approximate limit for advisable non-ventilation.

APPENDIX.

Recent Literature on Ventilation of Tunnels.

Arlberg.—Length, 6.4 miles. Arlberg R. R.
Engineering News, Mar. 18th, 1897, p. 175.
Railroad Gazette, Apr. 2d, 1897, p. 240.
Railroad Gazette, Jan. 13th, 1899, p. 29.

Baltimore.—Length, 3 700 ft., in 1892; 4 845 ft. ventilated, 1904. P., B. & W. R. R.
Engineering News, Oct. 20th, 1892, p. 362.
Railway Age, Mar. 18th, 1904, p. 471.

Big Bend.—Length, 6 500 ft. C. & O. Ry.
Railroad Gazette, Feb. 20th, 1903, p. 130.

Elkhorn.—Length, 3 000 ft. Norfolk & Western Ry.
Railroad Gazette, May 10th, 1901, p. 310.
Proceedings, Richmond Railroad Club, Apr., 1902.

East Mahanoy.—Length, 3 406 ft. P. & R. R. R.
Railroad Gazette, Mar. 8th, 1901, p. 154.

Giovi.—Length, 6.0 miles. North of Genoa.
Engineering News, Sept. 18th, 1902, p. 201.

Hoosac.—Length, 4.7 miles. Boston & Maine R. R.
Transactions, Am. Soc. C. E., 1890, Vol. XXIII, p. 288.
Railroad Gazette, Apr. 20th, 1900, p. 259.

Mersey.—Length, 2.0 miles. Liverpool.
Transactions, Am. Soc. C. E., 1890, Vol. XXIII, p. 288.
Engineering News, Oct. 18th, 1894, p. 310.
Minutes of Proceedings, Inst. of Civil Engineers, 1898, Vol. CXXXVI.
Engineering News, Feb. 13th, 1902, p. 132.

Metropolitan Tunnels.—London.
Engineering News, Oct. 18th, 1894, p. 310.
Engineering News, Apr. 14th, 1898, p. 237.
Railroad Gazette, Feb. 25th, 1898, p. 134.
Railroad Gazette, May 2d, 1902, p. 333.

Park Avenue.—New York, length, 2.0 miles. New York Central R. R.
Engineering News, Aug. 8th, 1901, p. 93.
Engineering News, Feb. 13th, 1902, p. 132.

Pracchia.—Length, 9 000 ft. Between Florence and Bologna.
Minutes of Proceedings, Inst. of Civil Engineers, 1898, Vol. CXXXVI.
Engineering News, Aug. 31st, 1899, p. 137.

St. Louis.—Length, 4 095 ft. Pennsylvania Lines.
Transactions, Am. Soc. C. E., 1890, Vol. XXIII, p. 288.
Engineering News, Aug. 4th, 1898, p. 79.

St. Clair.—Length, 6 000 ft. Grand Trunk Ry.
Railroad Gazette, Sept. 26th, 1890, p. 660.
Engineering News, May 12th, 1892, p. 489.
Engineering News, June 9th, 1892, p. 584.

Boston Subway Tunnel.—Length, 1.8 miles.
Engineering News, Feb. 4th, 1897, p. 76.
Railroad Gazette, Feb. 17th, 1899, p. 127.

Pennsylvania Avenue Subway.—Philadelphia, length, 2 711 ft. P. & R. R. R.
Transactions, Am. Soc. C. E., 1902, Vol. XLVIII, p. 470.

St. Gothard.—Length, 9.3 miles. St. Gothard Ry.
Minutes of Proceedings, Inst. of Civil Engineers, 1898, Vol. CXXXVI.
Railroad Gazette, July 14th, 1899, p. 504.

Simplon.—Length, 12.4 miles. Between Brieg and Iselle.
Engineering News, Aug. 13th, 1903, p. 134.
Engineering News, Aug. 20th, 1903, p. 154.

TRANSACTIONS
AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,
1904.

Paper No. 44.

VENTILATION OF TUNNELS.

By Francis Fox, M. Inst. C. E.

Having been invited to lay before the Engineering Conference of St. Louis some facts as to the ventilation of tunnels, the writer does so with less hesitation than would have been the case had the subject been the ventilation of buildings. In the latter case, it is impossible to please everybody, and one has to combat the views of persons who cannot stand the slightest movement in the air, and of others who evidently consider that fresh air is a thing to be abhorred (whereas a warm stuffy room deficient in oxygen, commends itself to them, as the one thing to be desired); but in dealing with tunnel ventilation, the engineer is independent of the idiosyncrasies of the passengers, and has to consider the subject only on a true scientific basis.

The increasing number of tunnels which are being constructed in all parts of the world—the splendid example of the great Simplon work, with its high scientific attainment, its wonderful progress and rapidity of construction, its magnificent ventilation, the kind and humane treatment of the men—all point to the necessity of the most careful consideration of a proper supply of fresh air, both during construction and eventual working under traffic.

In dealing with tunnels, it is not only those of great length which require attention; some of those, quite short in length, but

on a steep gradient, are amongst the most dangerous, and the writer is familiar with such an one in particular, which is only a quarter of a mile in length, constructed for a single line, but on a gradient of 2½ per cent. When a heavy train is ascending the gradient with locomotive throttle full open, and the wind blowing in at the lower end, causing the smoke to travel concurrently with the train, the condition of affairs becomes absolutely unbearable, and highly dangerous.

A list of the great Alpine tunnels (Table 1) with some of their leading features may be of interest as bearing upon this question.

TABLE 1.

	St. Gothard.	Mont Cenis.	Arlberg.	Simplon.
Length of tunnel, in miles	9.3	7.98	6.36	12.26
North or east portal above sea level, feet	3 639	3 766	4 296	2 254
South or west portal above sea level, feet	3 757	4 164	3 998	2 080
Highest level	3 788	4 248	4 300	2 314
Maximum grade in tunnel per 1 000	5.82	30	15	7
Maximum height of mountain above tunnel, feet	5 598	5 428	2 362	7 005

It is believed that the application of a large revolving fan was applied in railway work for the first time, in March, 1870, by the late Mr. Ramsbottom, to the Lime Street Tunnel of the London and North Western Railway in Liverpool, the length of which was 6 075 ft.; but such fans had been in operation, for mining purposes, for some time anterior to this. If, however, railway engineers would adopt for tunnels the same rules as are applicable to mines, much of the difficulty would disappear.

The Lime Street fan was 29½ ft. in diameter, and discharged its air into a high conical brick chimney, the diameter of which was no less than 54 ft. at its base; the quantity of air thrown was 431 000 cu. ft. per min., and was drawn from a point as nearly equidistant from the two ends as possible, the water gauge being only 0.14 in. It continued to work with a fair amount of success until the tunnel was cut open to daylight.

The construction of the Metropolitan Railway of London, and afterwards of the Metropolitan District Railway by the late Sir John Fowler, and the much-respected Past-President of the Institution of Civil Engineers, Sir Benjamin Baker, Hon. M. Am. Soc. C. E., were the first instances of railways placed in tunnels, under the streets of a city, and they depended, as they still do, upon openings into the streets and adjacent property, for the introduction of fresh air into, and the expelling of foul air from, the tunnel. The writer is of opinion that the action of the trains upon the air currents, and the constant variation of climatic conditions are so great, that, were not these railways about to be electrified, it would, in the interests both of the shareholders and of the traveling public, be absolutely necessary to apply mechanical power for putting the air of these tunnels into a satisfactory condition; the present system being inefficient, uncertain, and in calm weather almost useless. It is many years since these lines were constructed, during which time great advance has been made in the knowledge of the subject.

Gabriel James Morrison, M. Inst. C. E., in a paper* read before that Institution in 1876, gave much valuable information on the subject, and later experience has verified his statements.

It is desirable to ascertain, if possible, the standard of purity to be aimed at:

1.—In tunnels worked by steam locomotives, in which the products of combustion of fuel constitute by far the largest source of impurity.

2.—In tunnels worked by electricity, in which the chief source of contamination is the human lung.

Dealing with the first, the general consensus of opinion is, that provided the proportion of carbon dioxide (CO_2) does not exceed 20 parts in 10 000, no harm will be done, especially as the period during which passengers are exposed to this is but short.

The consumption of fuel in the firebox of the locomotive depends upon various considerations, such as the heating quality of the coal, the design of the firebox, the load hauled, and the steepness of the gradient; consequently, it is impossible to lay down any definite and accurate rule. Each tunnel must be dealt with on its

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* *Minutes of Proceedings*, Institution of Civil Engineers, Vol. XLIV, p. 18.

own merits, and the consumption of fuel per train-mile ascertained. Instances have been quoted where this has varied from 32 lb. per mile up to as much as 268 lb. in the case of a steep tunnel in Japan.

Allowing 29 cu. ft. of poisonous gas for each pound of coal consumed,* the volume of fresh air required, to maintain the atmosphere of the tunnel at the above-mentioned standard of purity, is ascertained as follows: The number of pounds of fuel consumed per mile, multiplied by 29, multiplied by 500 (that is 20 parts in 10 000) and divided by the number of minutes interval between the trains, will give the volume of air in cubic feet which must be introduced into the tunnel per minute, either by blowing in fresh, or by the exhaustion of foul air, to keep it in a sufficiently pure state to avoid inconvenience.

As an illustration—assume a tunnel to be one mile in length, a train passing through on the up and also on the down road every 10 minutes, the consumption of fuel being 40 lb. per train-mile, the volume of air required per minute will be:

$$\frac{40 \text{ lb.} \times 29 \text{ cu. ft.} \times 500}{5 \text{ minutes (interval)}} = 116\,000 \text{ cu. ft.}$$

Great are the disadvantages due to bad ventilation, such as injury to the employees, inconvenience to the passengers, danger of accident, slippery condition and rapid oxydation of the rails. On August 11th, 1898, in the long tunnel of Ponte Decimo near Genoa, which is on a 2½% grade, a train which, in consequence of the greasiness of the rails, came to a stand (the men on the engine being rendered incapable) ran back down the incline on the wrong road, and collided with a passenger train waiting its turn to pass through. The result was most disastrous, 12 persons being killed and 40 injured; all the result of bad air.

Serious results also obtained on the Pracchia Tunnel between Florence and Bologna, the gradient being the same, the length 9 000 ft.

The loss of weight in steel rails is also very serious, amounting in the case of Box Tunnel of the Great Western Railway to 2½ lb. per yd. of rail per annum, as compared with ½ lb. on the open-air portion of the railway.

Dealing with tunnels worked by electricity, a different method

* "The Ventilation of Tunnels and Buildings," by Francis Fox, *Minutes of Proceedings*, Institution of Civil Engineers, Vol. CXXXVI, p. 1.

of calculation has to be adopted, and is one upon which considerable difference of opinion may arise. No vitiation by combustion of fuel has to be provided for, but, on the other hand, the antiseptic properties of certain constituents of coal, which are doubtless of value, are wanting.

Air in a room which has been partially vitiated may not be very excessive in CO_2, nor give very bad results from a bacteriological point of view, yet it is very objectionable and injurious, producing languor and headache and, if inhaled for too long a period, disease; but in crowded assemblies where it has been breathed, rebreathed, and breathed again it is most pernicious.

The extent to which CO_2 may be added to pure air, without any very serious results for a short period, is remarkable; as high a proportion as 160 parts in 10 000 has been experimented with without injury, but, in combination with the products of respiration of a crowded audience, even 20 parts is excessive; it can only be regarded as an index of the toxic condition of the air.

The Volume of Air.—After lengthened investigations by English and French chemists and various learned societies, the volume of air required by each person per minute has been fixed at 30 cu. ft.

Air which has passed through the human lungs has been well designated "air sewage," is highly poisonous and charged with impure matter.

"Let any one gifted with the ordinary sense of smell, or who knows what fresh air means, enter almost any of the assembly rooms of public gathering after they have been occupied and let him describe the atmosphere he will meet on entering. It is charged with air sewage of the vilest quality, the imperfectly removed emanations from hundreds, if not thousands of human bodies, and the microscope shows that the air is highly charged with tuberculous and other dust."*

In consequence of the attention which has been called to the subject by Dr. Ransome and other men of eminence, the love of fresh air is extending amongst civilized communities, and, just as drunkenness gives way before the enlightenment of education, so will the terrible evils of foul air and bad ventilation be reduced, as the people become better informed on the subject.

The number of deaths in Great Britain resulting from tuber-

* Dr. A. Ransome, F. R. S., "Consumption a Filth Disease," *Medical Chronicle*, December, 1897.

culous diseases is steadily diminishing, due to the efforts being made by "The National Association for the Prevention of Consumption and other forms of Tuberculosis,"* of which His Majesty, King Edward VII, is Patron, and many other agencies.

The writer, who is familiar with America and has great respect for many of its institutions, and great affection for its people, ventures, in all kindness, to call attention to the need of more fresh air in most of their houses and buildings, and especially in their railroad cars. In consequence of the great extremes of temperature to which the United States and Canada are subjected, it is necessary to provide suitable heating arrangements, but these are carried to such an extreme, and with such an insufficient supply of fresh air, as to produce results and inconveniences of the worst order.

The discomfort to which the writer has been subjected in hotels, and railway carriages in the United States, during winter, has been such as to render a visit to that country very trying. The air is so intensely dry, the rooms are so unduly heated, and the supply of oxygen so insufficient, that he has found it necessary to sleep with a partially opened window, when the external air has been 15° below zero, while the interior heat of the building has been 80 degrees.

Assuming that the standard of purity:

(1) for steam-worked tunnels, should be 20 parts in 10 000 of CO_2,

(2) for electrically-worked tunnels, 30 cu. ft. of air per minute per passenger,

the writer now proceeds to consider the best methods for effecting the desired results.

Two of the earliest instances of ventilated tunnels are those of:

a.—The Severn Tunnel under the River Severn, on the main line to South Wales of the Great Western Railway; and

b.—Of the Mersey Railway under the River Mersey, between Liverpool and Birkenhead.

Plate XL shows two longitudinal sections or profiles of these tunnels which to a great extent are self-explanatory; but a few words may be desirable in each case.

The Severn Tunnel is 4 miles, 624 yd. in length, the gradient

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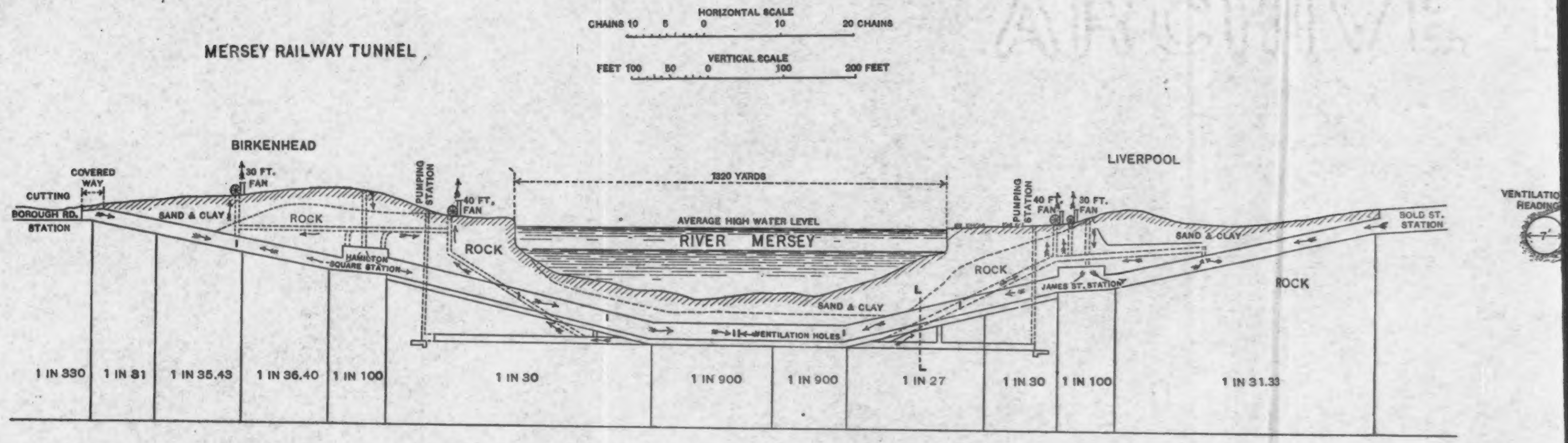
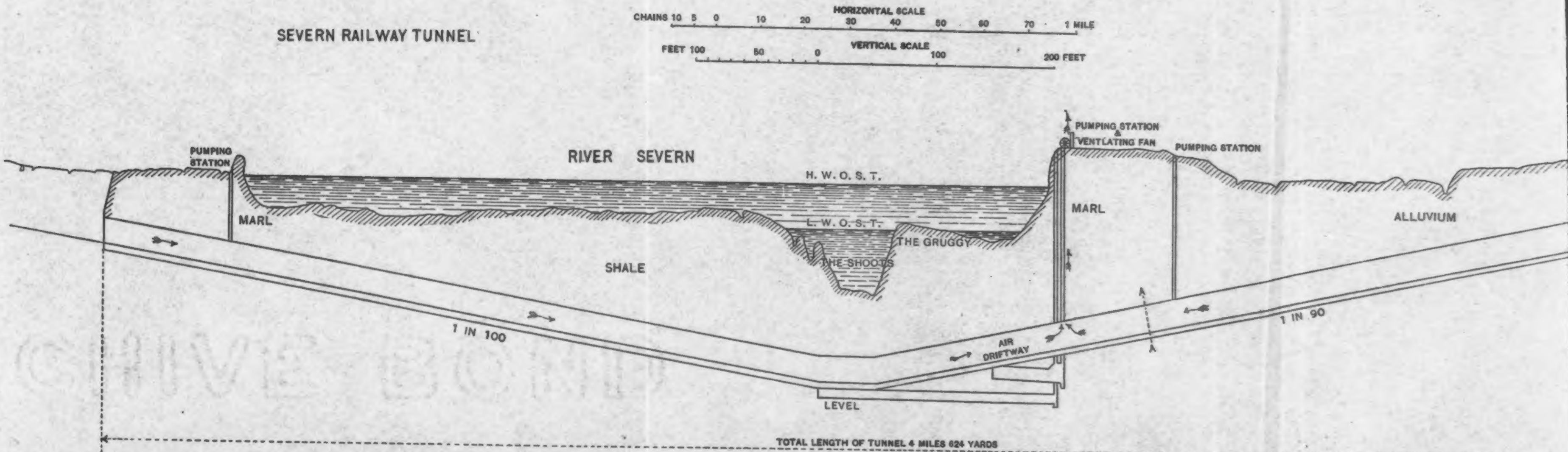
* 20 Hanover Square, London.

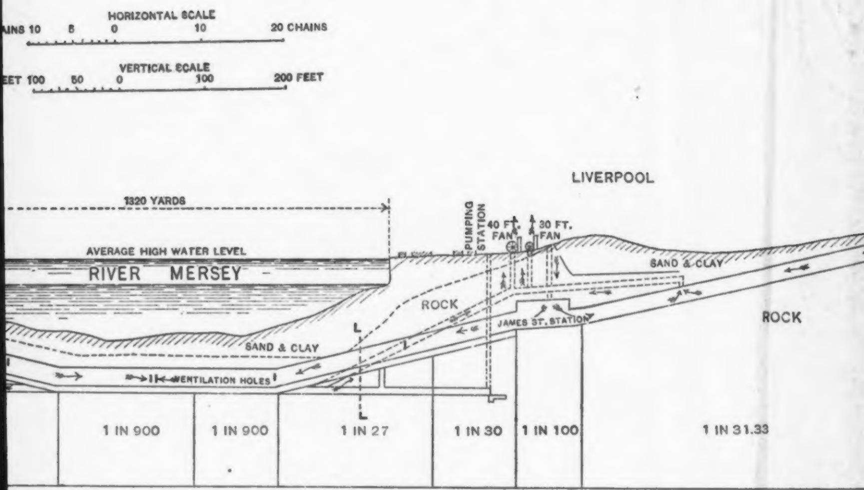
MERSEY RAILWAY TUNNEL

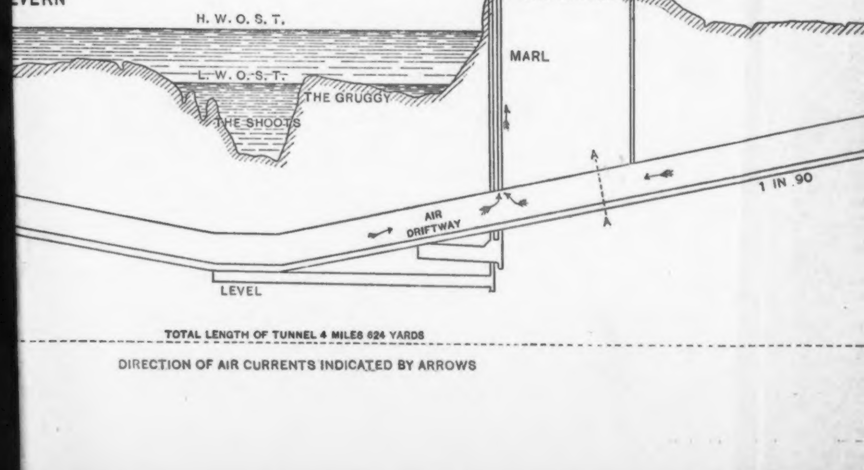


SEVERN RAILWAY TUNNEL



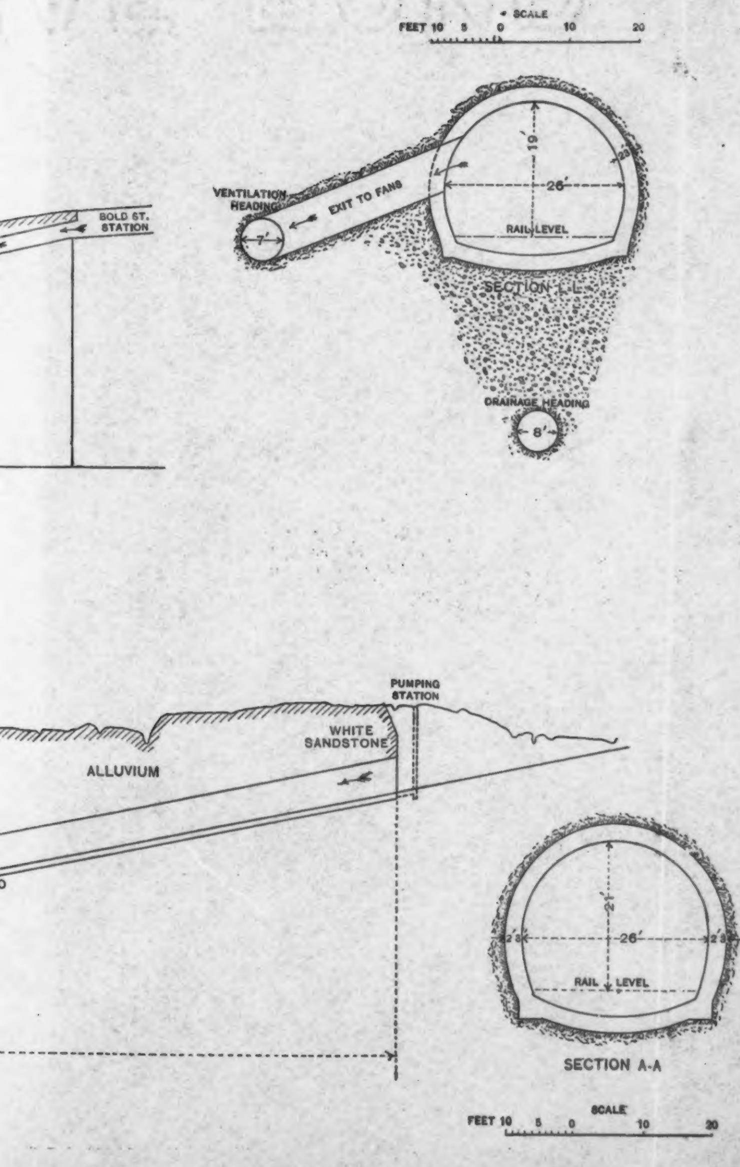
DIRECTION OF AIR CURRENTS INDICATED BY ARROWS





DIRECTION OF AIR CURRENTS INDICATED BY ARROWS

PLATE XL. VOL. LIV. PART C.
TRANS. AM. SOC. CIV. ENGRS.
INTER. ENG. CONG., 1904.
FOX ON
VENTILATION OF TUNNELS.



varying between 1 in 90, and 1 in 100, and has one ventilating shaft, placed as near the middle as the river would allow, or 1 mile, 1 210 yd. from the southern entrance, being thus 862 yd. from the center.

This is, of course, not an ideal position, as in certain directions of wind, the ventilating fan (which is a Guibal, 40 ft. in diameter by 12 ft. width of blade) is liable to draw its air mainly from one direction. Doubtless in time as the traffic increases, a modification of this arrangement will have to be effected.

The volume of air ejected from the tunnel by this fan is 400 000 cu. ft. per minute.

The Mersey Tunnel was a much more complicated problem to solve, owing to there being three stations underground to be provided for.

The rule that was laid down at the outset was, that fresh air must enter at the stations, so that the platforms should be kept fresh and pure. Consequently the vitiated air must be drawn from points midway between the stations. By this arrangement, fresh air would flow into the tunnel at the stations, by means of the footways, staircases and lift shafts; it would then travel along the tunnel getting more and more foul, as it proceeded, until it reached the part of the tunnel equidistant between stations, by which time it would have attained its maximum of impurity, when it would be swept down, by the drag of the fans, into the ventilation headings, and ejected into the open air at the fan chamber.

So long as these fans were kept running at their stipulated speed, and good coal was used on the locomotives, the ventilation results were excellent; but it is feared that, in consequence of financial requirements, both these were modified, without improving the condition of the atmosphere. As, however, the tunnel is now worked electrically, the volume of air required is much reduced.

Table 2 gives the sizes and outputs of each fan. That at Hamilton Street was found occasionally, when under a strong southwesterly gale, to be "drowned" in fresh air, consequently it had to be connected by drift with Hamilton Square Station, so as to be available when required to assist the other fans.

It is now 20 years since this method of ventilation was installed —during which period the excellent system, designed by Signor

Saccardo, has come into operation, and which modifies in a remarkable manner the arrangements required.

TABLE 2.—RESULTS OF EXPERIMENTS WITH VENTILATING FANS AT THE MERSEY TUNNEL.

Fan at	Diameter of fan, in feet.	Width of blade, in feet.	Number of revolutions per minute.	Area of drift-way, in square feet.	Water gauge, in inches.	Velocity of air, in feet per minute.	Volume of air, in cubic feet per minute.
Hamilton Street, Birkenhead.......	30	10	47	113	1.30	1 895	214 135
Shore Road, Birkenhead..............	40	12	45	41	2.50	3 288	134 685
James Street, Liverpool............	40	12	45	72	2.45	2 465	178 880
James Street, Liverpool............	30	10	60	60	2.30	2 062	123 720
Bold Street, Liverpool...............	12	5	240 to 300	No drift-way; the air being drawn direct from the underground station.	......	......	300 000
Total..........	......	......	......	....	......	......	951 420

This gentleman, the talented Engineer-in-Chief, of the Italian Railways, hit upon the happy idea of utilising the ventilating fan on the injector principle. Availing himself of the annular space existing between the gauge of maximum construction, and the interior section or intrados of the arch, he blows air in at the higher end of a tunnel, down the incline against the ascending traffic.

The volume of air entering the tunnel from the fan produces an induced current from the open mouth, according to the arrangements made, of from 30 to 100%, and as the apparatus requires no shaft, but is placed at the portal, the expense of installation is comparatively small.

The experiments the writer carried out at the Pracchia Tunnel on July 25th, 1894, on the railway through the Appenines between Florence and Bologna can with advantage be referred to here.

The Pracchia Tunnel is one of 52 tunnels on the main line

between Florence and Bologna, built about 1864 by the late Thomas Brassey, Assoc. Inst. C. E. These are single-line tunnels, on a gradient of 1 in 40. The traffic has increased greatly, and has to be worked by heavy locomotives. Under any condition of wind the state of this tunnel, about 9 000 ft. in length, is bad; but, when the wind is blowing in at the lower end at the same time as a heavy goods, or passenger train, is ascending the gradient, an almost insupportable state of affairs is produced. The engines, which are working with the regulators full open, often emit a large quantity both of smoke and steam, which travels concurrently with the train. The locomotives weigh 55 tons without tender. They have eight wheels, coupled, with a tractive force of 15 400 lb. The goods trains carry 250 tons of load, and have an engine in front, and one at the rear of the train; and when, from the humidity in the tunnels due to the steam, the wheels slip and possibly the train stops, the condition of the air is indescribable. A heavy train with two engines, conveying a Royal party and their suite, arrived on one occasion at the upper exit of the Pracchia Tunnel with both enginemen and both firemen insensible; and on another occasion, when a heavy passenger train came to a stop in the tunnel, all the occupants were seriously affected. On the occasion of the writer's visit to the tunnel, on July 25th, 1894, one of the brakesmen complained of being ill and of having fallen from his seat in one of the shorter tunnels.

The writer measured the volume and temperature of air with the following result. Before starting the fan, the tunnel was filled with dense smoke from end to end, the temperature being 107° fahr., with 97° of moisture, or nearly complete saturation. With the fan running, the thermometer indicated 80° (the temperature of the external air), or a fall of 27°, the moisture was normal, and the amount of air propelled by the fan was 164 000 cu. ft. per min., that by the induced current being 46 000 cu. ft., making a total of 210 000 cu. ft. of air per min. passing through the tunnel. The air is blown in at the upper end, and down the incline, the object being that an ascending train with its heavy trail of smoke and steam, may be freed at the earliest possible moment from the products of combustion. These results are remarkable, and the air of the tunnel is cool and fresh. This system, however, cannot be

applied to steam railways in which underground stations exist, as the effect of the current would be to blow the smoke to the platforms of the next station, the very part of the railway which should be kept in the best condition.

Since that date, the Saccardo system has been applied with great advantage to the St. Gothard and other tunnels, one of the most recent cases being that of the Tunnel de l'Albespeyre on the line between Langogne and Alais of the Paris, Lyons and Marseilles Railway.

The length is 4 915 ft., the gradient 2½%, the railway being for a single pair of rails. Trains have come to a standstill on the gradient and several cases of partial asphyxiation have occurred in consequence of the reduction of the speed of the train to 18 miles an hour due to moisture deposited on the rails.

A ventilating fan, 19 ft. in diameter, has been fixed near the upper end of the tunnel, and blows air down the incline, against the ascending train. The volume of air delivered, when running at full speed of 122 rev. per min., is 300 000 cu. ft., but, if workmen are in the tunnel attending to the permanent way, the velocity and corresponding volume are reduced to one-half.

The cost of the entire installation was about £2 000 and the adoption of the system has resulted in the complete solution of all the former difficulties.

A similar arrangement was adopted at the Cochem Tunnel in Germany, the annular arrangement of the Saccardo system being applied.

One of the most recent applications of the Saccardo system is that of the Elkhorn Tunnel in West Virginia.

This tunnel which is 3 000 ft. in length has an ascending gradient from its western portal of 2%, and is for a single line of railway.

The results are reported as being satisfactory, although the writer is of opinion that they would have been still better had the ventilating installation been placed at the upper end of the tunnel so as to blow down hill against the ascending traffic.

The writer is strongly of opinion, as stated in his paper already referred to, that the Saccardo system is the solution of ordinary tunnel ventilation; it is easily applied, no deep and expensive shafts,

or galleries are required, and the cost is of a comparatively trifling character.

When, however, the case of electrical "tube" railways, similar to those in London, has to be considered, the problem immediately assumes an entirely different aspect.

These railways consist of parallel tunnels, each for one line of way, and at certain points these two tunnels merge into one of double the size, to carry two lines of way, so as to provide cross-over roads and "switches." In addition to these, there are, at the stations, numerous passages connecting the two tunnels, with the necessary result, that anything like a well-regulated current of air, traveling as in mines in given directions, cannot be secured.

The train passing in one direction in one tube, pushes the foul air at *A* in front of it, to the "cross-over" tunnel from whence it is

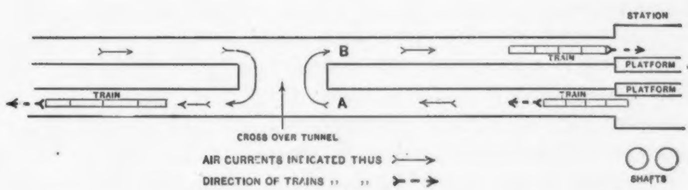


FIG. 10.

again sucked into *B* by the train going the other way, in the second tube. Thus the air is simply churned round and round, and very little of the foul air is actually dislodged, or fresh air brought in.

The problem is one of considerable difficulty and complexity, for if air be drawn by fan from the surface down one of the shafts, the tendency to some extent is for it to ascend the adjacent shaft.

If, however, the Saccardo system be utilised in conjunction with shaft ventilation, a great amelioration in the condition of the air can be secured.

The accompanying diagram (Fig. 11) will serve to illustrate this proposal.

The direction of the trains is shown by dotted arrows, whilst that of the air currents by full arrows. "Cross-over" tunnels do not exist at most of the stations.

The direction of the air currents is to a great extent regulated by that of the trains, owing to the latter fitting the tube with but little clearance, consequently they act as pistons.

Starting from the terminal, Station 1, the first object must be to keep the air at the platforms fresh, and this can be done by drawing air in from outside by Saccardo fans, as shown, at the further end of platforms. Fresh air is drawn down the shafts at Station 2, by the suction of the trains, and this is returned along the parallel tunnel toward 2 and 3 by the united efforts of the fans and trains.

As regards Shafts 3 and 4 the air in these will to a great extent be controlled by the piston action of the trains; the current will be constantly reversed, and this cannot be avoided unless the Saccardo system be more frequently introduced; this, however, is unnecessary, but at No. 5 it is again employed, and the same result for the next two or three stations will be repeated.

For every 100 000 cu. ft. of fresh air which is blown into the tunnel, or drawn in by the trains, an equivalent amount is ejected; the result being that, although this arrangement is far from ideal or perfect, it will maintain the air in a very fair condition.

As to the volume of air required, the following is the principle by which it is ascertained.

Assume Bank Holiday traffic, when the railway is crowded to the maximum

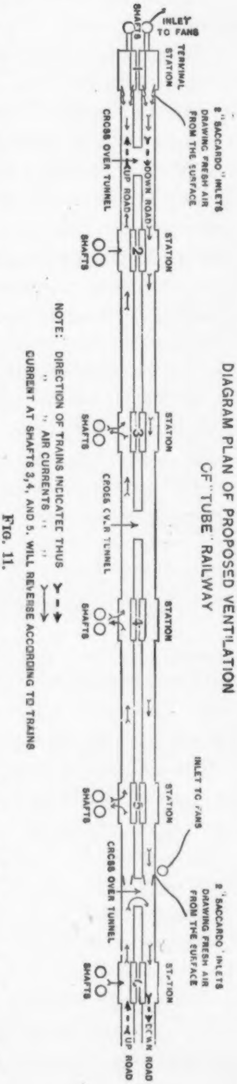


FIG. 11.

degree, trains running every $2\frac{1}{2}$ minutes in each direction, that is 24 trains each way or 48 in all, each train loaded to its full capacity, of say, 600 passengers, and traveling at a speed, including stoppages, of 18 miles per hour, three stations per mile, and each platform crowded with passengers.

For each mile of single tunnel, there will pass through in an hour 24 trains, each with 600 passengers, and requiring 30 cu. ft. of air per passenger per minute, but each train is on the one-mile length for a period of only $\frac{60}{18}$ minutes $= 3\frac{1}{3}$ minutes.

The result is that for each tube, for each mile, the quantity of air required per minute is 69 000 cu. ft.

When the trains and platforms are less crowded and the traffic assumes its normal volume, the quantity of air required can be proportionately reduced.

Arrangements should be made for the free passage of vitiated air from the carriages into the tunnel, otherwise the congested condition of the air on arriving at the terminus will be aggravated.

The writer hopes that, as more attention is being paid to the system of ventilation generally, the great loss of life occurring at present, from tuberculous diseases, may be very greatly reduced; and he congratulates his American friends upon being the first to put into operation penal enactments against the objectionable habit of spitting, which, in railway tunnels as elsewhere, is fraught with evil.

TRANSACTIONS

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

DISCUSSION ON VENTILATION OF TUNNELS.

By Messrs. Charles C. Wentworth, Thomas H. Johnson, P. F. Brendlinger and Charles S. Churchill.

Mr. Wentworth.

Charles C. Wentworth, M. Am. Soc. C. E., Roanoke, Va. (By letter.)—It may be of some interest and utility to consider the analysis that was used in proportioning ventilating plants such as were installed at the Elkhorn and Big Bend Tunnels in Virginia, which are described by Mr. Churchill.

As the production of the necessary air currents from one end of the tunnel, without at all decreasing the tunnel clearance, by the blowing apparatus or nozzle, appeared to be a novel procedure, it was necessary to make certain assumptions in proportioning these plants, which were founded on judgment rather than experience; but the results of these installations have shown that these assumptions were not unwarranted, and the whole may well be used as a basis for future tests to gather data for a more complete solution of the problems involved.

Beside the non-contraction of the tunnel clearance already alluded to, it was decided, at the outset, that no air, or as little as possible, should be drawn into the tunnel by the blast, but that all the air delivered by the blast should pass entirely through the tunnel unhampered except by the passage of trains. It seemed better to give all the ventilating air its velocity positively by fans rather than to use the blast to accelerate an additional quantity of still air by friction, with a certain amount of loss of mechanical efficiency to the whole plant.

Mr. Wentworth.

Owing to this assumed condition, the theory of the injector does not apply to the production of such an air current, as there is no second body acted upon by the blast by impact or otherwise; but it is the air delivered by the blast that is itself to continue in motion, at a reduced rate of speed, through the tunnel.*

The total resistance to the passage of air through a tunnel, when no train is passing through it, is given as $KNLV^2$; in which K is the resistance of friction in pounds for each square foot of the inner surface of the tunnel to air passing thereby at a velocity of 1 ft. per min.; N is the length of the perimeter of the tunnel measured along the walls and across the track; L is the length of the tunnel, and V is the velocity of the air current. This total resistance divided by the area of the cross-section of the tunnel, A, gives the force, P, in pounds per square foot of tunnel section, necessary to maintain the velocity, V, of the current. We can then put

$$P = \frac{K\,N\,L\,V^2}{A} \qquad (1)$$

and for the foot-pounds of work per minute necessary to maintain the current, we have,

$$F = P\,A\,V = K\,N\,L\,V^3 \qquad (2)$$

Calling the area of the blast outlet C, and the velocity of the blast S, we have for the foot-pounds of energy per minute contained in the blast (the weight of 1 cu. ft. of air being 0.08 lb.),

$$F_1 = \frac{C\,S^3}{2\,898\,000} \qquad (3)$$

As the volume of air flowing through the tunnel per minute is equal to the volume supplied by the blast in the same time, we have $CS = AV$; and Equation 3 may be written

$$F_1 = \frac{A\,V\,S^2}{2\,898\,000} \qquad (4)$$

When the velocity of the blast, after leaving the blast outlet and entering the tunnel, becomes reduced to V (the velocity of the current in the tunnel), the area of the blast is equal to the area of the tunnel, and the energy per minute remaining in it at that time is

$$F_2 = \frac{A\,V^3}{2\,898\,000} \qquad (5)$$

Now, by subtracting Equation 5 from Equation 4, we find the amount of energy per minute rendered available for maintaining the current in the tunnel; a portion of which energy (depending on the efficiency of the blast as a machine for doing useful work)

* In this discussion dimensions are expressed in feet, areas in square feet, velocities in feet per minute, weights in pounds per square foot.

can be equated with Equation 2. Assuming this efficiency at 50%, we have, Mr. Wentworth.

$$\frac{A\ V\ S^2 - A\ V^3}{5\ 796\ 000} = K\ N\ L\ V^3 \ldots\ldots\ldots\ldots\ldots (6)$$

from which, for the ratio between the velocities of the blast at the outlet and of the tunnel current, we have

$$R = \frac{S}{V} = \sqrt{\frac{5\ 796\ 000\ K\ N\ L}{A} + 1} \ldots\ldots\ldots\ldots\ldots (7)$$

The numerical value of K is somewhat uncertain, but has been taken for brick-lined tunnels, making an allowance for the greater roughness of the track, as 0.00000000285; and the perimeter, N, of an ordinary single-track tunnel, may be expressed as $3.8\sqrt{A}$. Making these substitutions, we obtain,*

$$R = \frac{S}{V} = \sqrt{\frac{.063\ L}{\sqrt{A}} + 1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

and finally, as $CS = AV$, for the required area of the blast outlet in square feet,

$$C = \frac{A}{R} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

It appears from Equations 8 and 9 that there is no especial velocity of blast required in order that all the air delivered by it shall be driven through the tunnel, but that the area of the blast outlet is a function of the length and sectional area of the tunnel only. As the power and resistance are both proportional to the square of the velocity, their ratio remains constant.

Care was taken at Big Bend to make the center of gravity of the blast outlet correspond in position with the center of gravity of the tunnel section, with the result of an apparent elimination of all eddy currents.

Thomas H. Johnson, M. Am. Soc. C. E., Pittsburg, Pa. (By letter.)—Mr. Churchill has described the means resorted to for the improvement of the ventilation in various tunnels in the United States and abroad. The paper is largely a collection of facts, without attempting to demonstrate the governing principles. It, therefore, offers little opportunity for discussion. Mr. Johnson.

There is, however, one statement in the paper which needs correction, for it has appeared in American technical literature un-

* As originally deduced these equations were

$$R = \frac{S}{V} = \sqrt{\frac{0.042L}{\sqrt{A}} + 1}.$$

$$C = \frac{A}{1.2\ R}.$$

In this discussion, the factor, 1.2, has been put inside the radical, the ultimate numerical value of C remaining practically unchanged.

Mr. Johnson. challenged, for several years past. The writer refers to the description of the ventilation of the St. Clair Tunnel.

Mislead by the published accounts of this tunnel, while pursuing investigations on the subject, the writer requested the General Manager of the Pennsylvania Lines to procure from the proper officer of the Grand Trunk Railway such information as might be available in reference to the working of the plant, and the degree of success attained in ventilating the tunnel. In reply, under date of May 2d, 1904, Mr. Frank W. Morse, Third Vice-President of that road, says that "it has no artificial ventilation."

He then quotes at some length from a report made in 1893 by Joseph Hobson, M. Am. Soc. C. E., Chief Engineer of the Grand Trunk Railway, who, after stating the results of his observations and studies of the movement of air in the tunnel, concludes that artificial ventilation is not needed, and says,

"In fact, I say without the slightest doubt, that, could the accidental parting of freight trains be prevented, the ventilation would be all that could be expected or desired." Speaking of artificial means (which he does not think necessary), Mr. Hobson says "the most effective is a rotary fan, but the most powerful of these, that I have been able to learn anything about, give results little better than those secured by the trains running through the St. Clair Tunnel."

The misconception as to the facts probably originated in the article in the *Railroad Gazette* of September 26th, 1890 (cited by Mr Churchill). That article contained a long description of the tunnel, methods of construction, progress made, etc. It was written before the tunnel was fully completed and put in service. It says, "The tunnel will be ventilated by two Root blowers of 10 000 cu. ft. per min. capacity." Evidently the "will be" did not become reality.

In several instances cited, it has been sought to improve the ventilation by substituting coke for coal. The combustion of coal in the firebox of a locomotive gives off about 30 cu. ft. of carbonic gases per pound of coal, of which ordinarily two-thirds will be carbon dioxide and one-third carbon monoxide, the proportions varying somewhat with the condition of the fire and the state of combustion.

With coke the relative quantity of the monoxide produced is much greater, and as that gas is the more deadly of the two, the change in fuel will make the conditions worse instead of better, so far as respiration is concerned.

Unburned carbon in the smoke of soft coal, while it obscures the vision and causes some personal discomfort, is practically harmless from a physiological point of view. But, when, as in the case of the Park Avenue Tunnel in New York City, safety depends on clearness of vision, it may be allowable to use coke; but only in con-

nection with such aids to ventilation as will insure proper dilution and prompt removal of the gases. Mr. Johnson.

What is a proper dilution? The question is answered by the investigations of a Royal Commission in Italy in the course of their study of the practical working of the Saccardo apparatus at the Pracchia Tunnel, cited by Mr. Churchill. They collected and analysed samples of the gases in the smokestack, of the air in the cab and of the air in the tunnel. At the same time, the men on the engine were required to report whether, in their judgment, they found the air good, bad, or very bad. The result, when the reports of the men and the analyses were compared, was that the Commission fixed the following limits, *viz.:*

When $CO_2 + CO$ does not exceed 1%........"good"
" " " " " " 2%........"bad."

And, by an unfortunate accident, they were enabled to say that at 3%, it becomes "fatal."

While the proportion of 2% is designated as "bad," it may be breathed without serious trouble, beyond the temporary discomfort, provided the time of exposure does not exceed seven or eight minutes.

When coke is the fuel, with its larger proportion of the more deadly monoxide, these limits would have to be materially reduced. A man cannot live long in an atmosphere containing 1% of the monoxide; dies quickly in an atmosphere containing 2%, and suddenly in an atmosphere containing 10 per cent.

Whenever the conditions in a tunnel become bad, the men on the locomotive are the first to feel the effects of it, because the air entering the cab will usually contain an undue proportion of the gases from the smokestack, which have not as yet become thoroughly diffused through the whole section of the tunnel. The fireman will suffer sooner than the engineer, because his more active physical exertion demands a larger supply of oxygen, and he succumbs more quickly when that supply is cut off or diminished.

Therefore, in installing a plant for artificial ventilation, it is not sufficient to consider the problem only from the point of view of clearing the tunnel in a specified time, but it should first, and above all, protect the lives and health of the men while the train is in the tunnel. Clearing the tunnel of smoke after the train has passed out, and before the next one is due, is also important, but only from the point of view of preventing the second train from entering an atmosphere already surcharged with noxious gases.

It may very well be, and no doubt will be so found in many cases, that the plant which clears the tunnel in a reasonably short time after the train has passed out, will also so far ameliorate the

Mr. Johnson. conditions while a train is in the tunnel, that the result will prove to be satisfactory. But a plant that is capable of producing "good" conditions with a train in the tunnel will always be able to clear the tunnel quickly after the train has passed out. It would seem, therefore, that the former is the more important feature of the problem.

It seems to the writer that Mr. Churchill has not sufficiently emphasized the weak point in all systems of ventilation by shafts located at one or more intermediate points, and with or without mechanical aids.

A shaft, without aid, depends for its action on the difference of temperature between the interior of the shaft and the outer air. In summer, when the walls of the shaft are cooler than the outer air, the draft will be downward. In winter, the reverse is the case, and the draft will be upward. In spring and autumn, there will be many days when there is little or no difference of temperature, and then the shaft will be inoperative and the air stagnant, except as the passage of trains may agitate it and create temporary movement.

With two shafts the result is worse, for the draft of each shaft will be supplied by inflow at the nearest portal, and the intermediate section remains stagnant.

In the case of a single shaft, unequal conditions, as to temperature and barometric pressure at both ends, will determine the course of the inflow wholly from one portal or the other, with the result that one-half of the tunnel will be well ventilated and the other half not.

If both portals are at unequal elevations, and, especially, if one portal is higher than the base of the shaft, that half of the tunnel toward the lower portal will be the better ventilated most of the time.

The Hoosac Tunnel is unique in having both portals at the same level with a summit of grades at the base of the shaft in the middle of its length. The shaft is also of larger diameter and greater depth than is usually the case; therefore, the ventilation of this tunnel has been better than is usually found in this type.

The addition of a fan helps matters in so far as it makes a positive up draft at all times; but it does not relieve the difficulty arising from unequal atmospheric conditions at both ends.

The plan of forcing air into one end, and creating a continuous current throughout the whole length of the tunnel, as designed by Mr. Saccardo and by Messrs. Churchill and Wentworth (the two systems differ only in the form of the air chamber), is the only one that gives full control of the situation under all circumstances.

It is positive in its action;

It is adaptable to varying conditions, by changing the speed of the fan;

It admits of economy of power by stopping the fan during intervals when there are no trains. Mr. Johnson.

The governing principles have been well defined by the work of the Italian Commission, and a plant can readily be designed to meet the requirements of any given case.

It is matter of regret that the complete report of that Commission has not been published. An abstract of it was published in the *Bulletin* of the International Railway Congress in 1899. That abstract, however, did not do justice to the report, nor give an adequate idea of the magnitude of the work done, or the thoroughness with which a large mass of experimental data has been digested, and the fundamental principles reduced to mathematical equations, covering all possible variations in the conditions of the problem.

The data and formulæ contained in the report enable one to determine for any given case and for different lengths of train the pressure required at one end of the tunnel to produce a given velocity of current with the train at rest, or at different speeds, or with the tunnel free of trains; to compute the velocity induced by the train and the pressure in front necessary to counteract or annul it; to determine the area of orifice and pressure in the air chamber required to produce the needed pressure and volume in the tunnel; and to determine the size and speed of the fan and the power to drive it.

In fact, the report is a masterly and exhaustive treatise on the subject, which should be made available to the profession at large.

The writer has read Mr. Fox's paper with great interest, and notes two points which seem to call for further remark.

In regard to the allowable degree of impurity, the author fixes upon 2% of CO_2, and takes no note of CO, which is always present in greater or less quantities, owing to imperfect combustion in the firebox, and which is the more deadly of the two.

The Royal Italian Commission, which made an exhaustive study of the Saccardo apparatus at Pracchia in 1894, found that the carbon gases thrown off by the locomotive were usually composed of two-thirds CO_2 and one-third CO; these proportions varying, however, with different conditions in the firebox. In exceptional instances, the CO rose as high as one-half of the whole, and, in others, fell as low as one-tenth; but, in the majority of cases, the proportions differed but little from the general average.

The results found by the Commission have already been given in this discussion.

It may be that the author had the fact in mind that air containing 2%, CO_2 + CO, although characterized as "bad," may be breathed seven or eight minutes without harm, and meant to fix a

Mr. Johnson. limit of impurity rather than a standard of purity. If the latter is sought, it should not be placed above 1%; and in ascertaining the existing conditions, if the amount of CO_2 only is determined, it must not be forgotten that CO is also present, and the allowable amount of CO_2 should not exceed two-thirds of the respective limits.

The determination of the amount of gases present in the air is the work of a chemist, rather than that of an engineer. But for an ordinary railway tunnel, in which only the gases emitted by the locomotive need be considered, it is not necessary to resort to chemical analysis to obtain the information desired. In the report of the aforesaid Commission, it is pointed out that the rise in temperature, caused by the passage of a train, is in direct relation to the degree of impurity created by the gases thrown off.

The rise in temperature is, of course, due to the heat carried off by the gases discharged through the smokestack, and by the exhaust steam, and to the heat radiated from the sides of the boiler. These sources of heat depend on the rate of combustion in the firebox and must be mutually proportional to each other. Hence it will be seen that the increment of temperature corresponding to any given degree of impurity will be constant.

For the average conditions prevailing at Pracchia, it was found that

When $CO_2 + CO = 1\% \therefore t = 11.3°$ cent. $= 20.3°$ fahr.
" " " $= 2\%$ $= 22.9°$ " $= 41.2°$ "
" " " $= 3\%$ $= 62.8°$ " $= 62.8°$ "

Under different barometric conditions, these figures would be slightly modified, but so slightly that they may be taken as they stand, as a simple means of testing the condition of a tunnel in respect to ventilation, without resorting to direct analysis of the air.

In regard to whether the artificial current should be directed with or against the advancing train, the writer wishes to add his voice to that of Mr. Fox in favor of the latter direction. There are two reasons for this:

First.—The system of blowing with the train is objectionable from the standpoint of an operating officer, for the reason that the speed of all trains must be reduced below that of the air current, thus creating a perpetual slow order to forever hamper the movement of trains.

Second.—To attain equal degrees of dilution, that is to say, to reduce the air to the same standard of purity, in both cases, requires a larger expenditure of power when blowing with the train than against it, as will be apparent from a brief consideration.

The gases emitted from the smokestack in a unit of time will be diffused through the volume of air encountered by the train in the same unit of time. Hence, when blowing with the train the

Mr. Johnson.

gases are diffused through a volume of air measured by the difference of velocities of the train and current, and, in the other case, by the sum of the velocities.

Hence, in order that the relative velocity of train and air shall be the same in both cases, the absolute velocity imparted to the air, when blowing with the train, must equal the speed of train plus the required relative velocity; and when blowing against the train the absolute velocity need only equal the speed of train minus the required relative velocity; hence the greater power required in the former case.

As more forcibly illustrating this point, the writer quotes from the report of the Royal Commission, before referred to, as follows:

"At first view it may appear that the artificial ventilation could be conveniently effected by pushing the air behind the train in such way that the current produced will outrun the train, thus realizing an economy in consequence of the piston action exerted by the train.

"To demonstrate how irrational such a system will be, with double-header trains traversing the 'Appenine Tunnel,' it is sufficient to report the following table:

Class of Train.	Velocity in Meters per Second.			Pressure, in Millimeters of Water.				Work in Effective C. V.			
	Of the train. W	Of the current. V	Relative. $W \pm V$	Required in front of the nozzle.	Difference of pressure at front and rear of train.	Produced in rear of nozzle.	Required in the air chamber.	Utilized in ventilation of the train. L_u	Corresponding to difference of pressure produced by the train. L_t	Pneumatic work required at the fan. L_p	Coefficient of useful effect of the system. $\frac{L_u}{L_p \pm L_t}$
Slow *a*..	5	0	5	23.8	23.8	·3.2	36.8	36.7	36.7	57.6	0.389
Slow *b*..	5	10	5	97.5	29.3	0.7	200.4	45.1	45.1	763.0	0.063
Fast *a*..	10	2	8	22.5	25.3	5.4	33.9	62.3	77.9	43.8	0.491
Fast *b*..	10	18	8	254.6	37.9	0.8	545.0	93.4	116.7	3428.0	0.028

a = Artificial current against the train.
b = " " with " "

Hence, from both operating and engineering standpoints, the direction of the current should be opposed to that of the train.

Mr. Brendlinger.

P. F. Brendlinger, M. Am. Soc. C. E., Philadelphia, Pa.—The speaker has read Mr. Churchill's paper with great interest, and must confess that it seems to be the best system for ventilating a single-track tunnel that has yet been put to a practical test. He is now watching with keen interest the proposed operation of this system applied to the new tunnel which he, as contractor, constructed for the Pennsylvania Railroad Company on top of the Allegheny Mountains at Gallitzin, Pa., about eleven miles west of Altoona, Pa. The Pennsylvania Railroad Company had, up to 1902, two double-track tunnels at this point, about 500 ft. apart—one of standard size, 29 ft. at spring line, built in 1898, and used exclusively for east-bound traffic; the other tunnel, built in 1851, is only 24 ft. wide at spring line, and used exclusively for west-bound traffic. There is no trouble from smoke and gas in the east-bound tunnel, as the traffic goes down grade, and the trains would descend by gravity alone if permitted; besides the tunnel is only 1 600 ft. long. In the west-bound tunnel, however, which is 3 600 ft. long and has a continuous ascending grade of 1% for the whole length of the tunnel, the gases and smoke are exceedingly disagreeable to passengers on the trains and almost suffocating to section hands and train crews. In 1902, the Company awarded the contract for building a single-track tunnel parallel to and 80 ft. center to center from the present west-bound tunnel. This tunnel has the same length and grade as the old one. It was completed in May, 1904, and put in service about July 1st. The old tunnel was abandoned temporarily for examination and for making any slight repairs that might be needed. After about two weeks' use, it was found that there was great danger of asphyxiation to the freight-train crews, on account of having to use two engines in front and a pusher besides, and the necessary slow movement; and, consequently, the old tunnel was again put in service for freight trains, the new tunnel being only used for passenger trains.

The Pennsylvania Railroad Company has thoroughly investigated Mr. Churchill's method of ventilating tunnels, and must be well satisfied with its workings, because it is now installing his plant at the east end of the new tunnel, and, of course, intends to blow the gases and smoke ahead of the train.

There is another element of danger besides that of asphyxiation and suffocation to train crews, section men, and the traveling public from gases and smoke, and that is the safety of the tunnel itself. It was found in examining the old tunnel, when it was temporarily abandoned, that the smoke and gases, in combination with water, had very considerably affected the brick arch. The tunnel is lined with rough-point mountain sandstone to a height of about 45° in the haunches, and above that with five rings of brickwork. The

water which seeps through the brick arch absorbs the gases from the engines and runs down the sides of the arch to the ditch. A black fungus grows up the side of the stonework; it does not affect that, but as soon as it reaches the brick arch, the brick is eaten out and destroyed. It occurs to the speaker that there is a sulphuric or sulphurous acid generated by combination with the sulphur fumes or gases from the engines with the water from the tunnel, which absorbs the black smoke from the engine, making a spongy black fungus, remaining attached to the walls, and thus permitting the acid to remain on the arch and eat or dissolve the clay forming the brick. This fungus does not approach nearer than 3 or 4 ft. to the line of blast from the stack of the engine, nor does it occur where the tunnel is dry. **Mr. Brendlinger.**

CHARLES S. CHURCHILL, M. AM. SOC. C. E., Roanoke, Va. (By letter.)—Mr. Brendlinger refers to the ventilating plant being installed at Gallitzin Tunnel on the Pennsylvania Railroad. Since the writing of the paper, this installation has been practically completed. It is of the same type as that in use at Elkhorn Tunnel on the Norfolk and Western Railway, and at Big Bend Tunnel on the Chesapeake and Ohio Railway. **Mr. Churchill.**

Mr. Wentworth has correctly shown by the formulas which he has given, that the system of ventilation, as used at Elkhorn Tunnel on the Norfolk and Western Railway, and at Big Bend Tunnel on the Chesapeake and Ohio Railway, is dependent for its successful operation upon the proper proportioning of the nozzle and area of air blast; but that this in turn is a function of the length and sectional area of the tunnel under consideration. When a train is in the tunnel, the cross-section of that also must be considered as modifying the area of nozzle outlet.

Mr. Johnson quotes at considerable length the results of an investigation by a Royal Commission of Italy on the working of the Saccardo apparatus at Pracchia Tunnel, as reported in the *Bulletin* of the International Railway Congress, April, 1899. Unfortunately, however, this report is confined to this tunnel only, and it is, therefore, the record of a machine successfully operated at this single tunnel, but with important items, such as area of cross-section of tunnel, area of cross-section of train, and volume of air actually delivered entirely through the tunnel under different conditions, not directly given. It is, therefore, very apparent that any conclusions drawn therefrom will be applicable only to a tunnel having a similar cross-section relative to the trains passing through it.

This report, however, states that the relative area of cross-section of tunnel and train at Pracchia is expressed by the formula:

$$\frac{\text{Cross-section of Tunnel} - \text{Cross-section of Train}}{\text{Cross-section of Tunnel}} = 0.84.$$

Mr. Churchill. This equation shows that the section of Pracchia Tunnel is six times that of the train. Compare this with Elkhorn Tunnel, with ventilating plant at lower end, but with section of tunnel only $1\frac{8}{10}$ times that of train; or with Big Bend Tunnel, with ventilating plant at upper end, but with section of tunnel only $1\frac{9}{10}$ times that of train; and it is at once discovered that the problems met with and successfully solved at these two tunnels are entirely different from that at the Italian tunnel.

Abstracting further from this report, it is found that notwithstanding the large space existing between a train and the walls of Pracchia Tunnel, thereby making the resistance to the ventilating air current quite low, nevertheless, with an up-train running at 10 miles per hour and with air forced against it at a recorded speed of 532 ft. per minute, this ventilating current becomes *nil* on the entrance of a train into the lower end of the tunnel. It is further stated that the general maximum velocity of the ventilating current is 590 ft. per minute.

Now, carefully noting all these conditions at Pracchia Tunnel, let us consider for a moment Elkhorn Tunnel, where trains pass through that leave but little space between them and the walls of the tunnel, the trains often being operated by three heavy locomotives, and the problem is seen to be entirely incomparable with that at Pracchia. The relative result accomplished, however, is shown by time necessary to clear the tunnels under the conditions named. At Pracchia, in the test referred to, it is given as 12 minutes after train clears—in other tests, as 18 minutes; at Elkhorn, as shown in the writer's paper, the tunnel is generally clear at about the time the train leaves it.

In discussing the effect of gases from a locomotive on life and comfort, it appears that no consideration has been paid to anything other than CO_2 and CO. This view is not wholly correct. An average of fourteen tests of the products of combustion from the stack of a boiler furnace gives the following results:

CO_2	14%
CO	1%
N	76%
O	9%

These latter two gases, N and O, are probably combined as hot air, the 9% of oxygen uniting with 36% of nitrogen, thus leaving 40% of N, which, with 14% of CO_2 and 1% of CO, makes a total of 55% of gases inert or poisonous which cannot support life, and, therefore, cannot be breathed without harmful results.

Inasmuch as 55% of the discharge from the smokestack of a locomotive is useless for the support of life, and the balance, or

45%, is hot air mixed with unburned carbon or soot, together with steam, and considering the fact that these inert gases have been known to collect in a tunnel to such an extent as to put out a light, while the temperature of the air has, in a few minutes, been raised 30°, the writer remains fixed in the opinion that all the products from the smokestack should be considered in treating of tunnel ventilation rather than carbonic gases alone. Mr. Churchill.

It is beyond dispute that conditions of tunnel ventilation to be met with at this time on American railroads are distinctive in character. Each case must be taken up in detail, and conditions of traffic and speed of trains, as well as relative cross-sections of tunnel and train, will enter into the solution of each case, in order to secure the particular degree of purity desired in the tunnel atmosphere and around the train.

The question is often asked: What is the cost of operating a ventilating plant? Directly after the installation of the ventilating plant at Elkhorn Tunnel, the loading of east-bound coal trains was increased about 100 tons. This is equivalent to a saving of 4 east-bound trains per day on a run of 11 miles.

The total saving in operating expenses per month from decreased train mileage amounts to..................	$1 716.00
Against this is to be charged the cost of operating the ventilating plant per month, which is..................	270.00
Net saving in operation on account of installation of ventilating plant at Elkhorn Tunnel amounts per month to about..	$1 446.00